

Probing Cosmic Chemical Evolution with MeV Photons



Dieter H. Hartmann
Clemson University

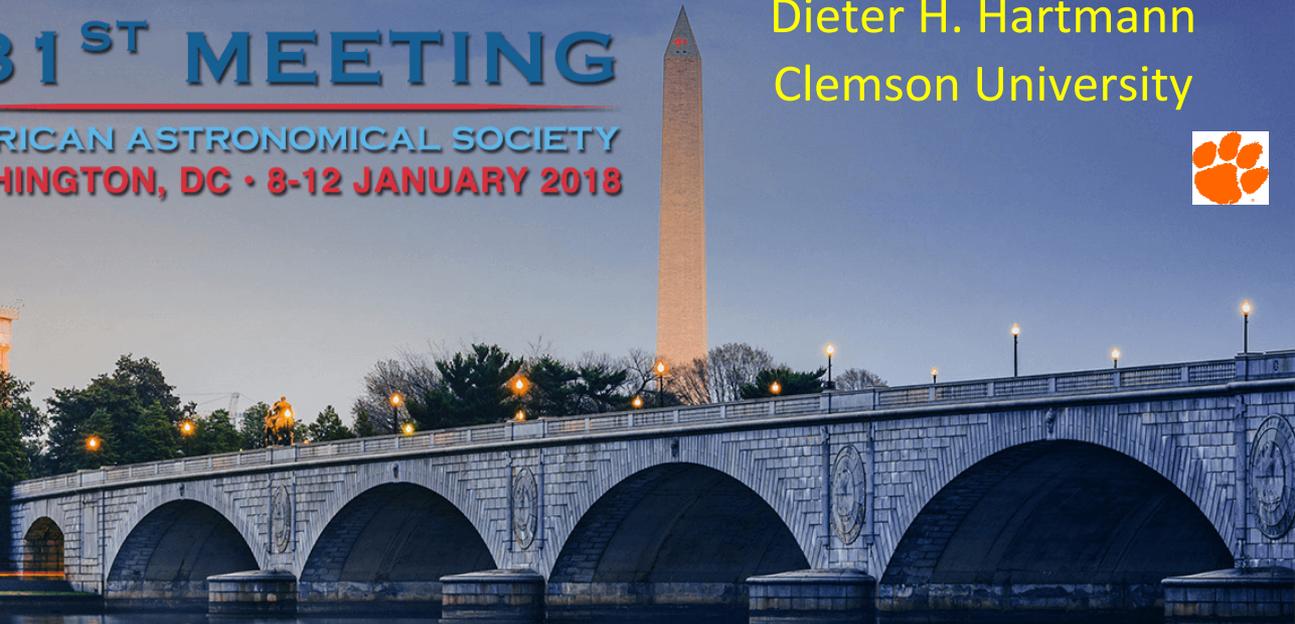
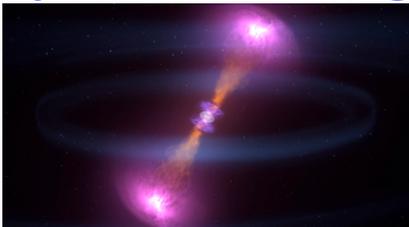


Photo Credit: www.suddath.com

Splinter Meeting

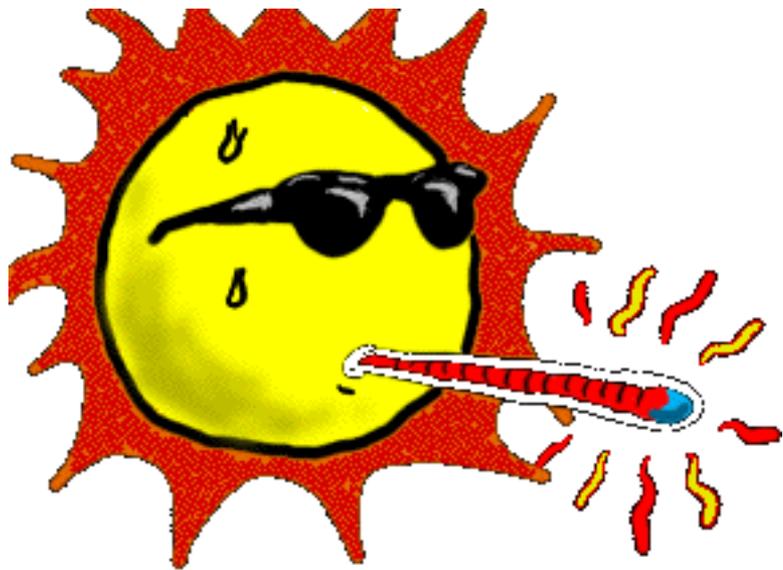


Astrophysical Extremes and Life Cycles of the Elements: Opportunities from the MeV Gamma-ray Sky

Wednesday, January 10, 2018 from 1:00 pm - 4:30 pm

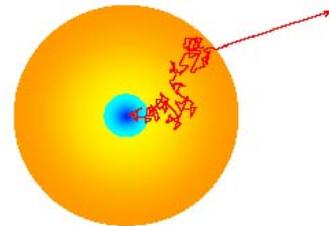
National Harbor 8 at the Gaylord National

SOC: Fabian Kislak, Andreas Zoglauer, Roopesh Ojha

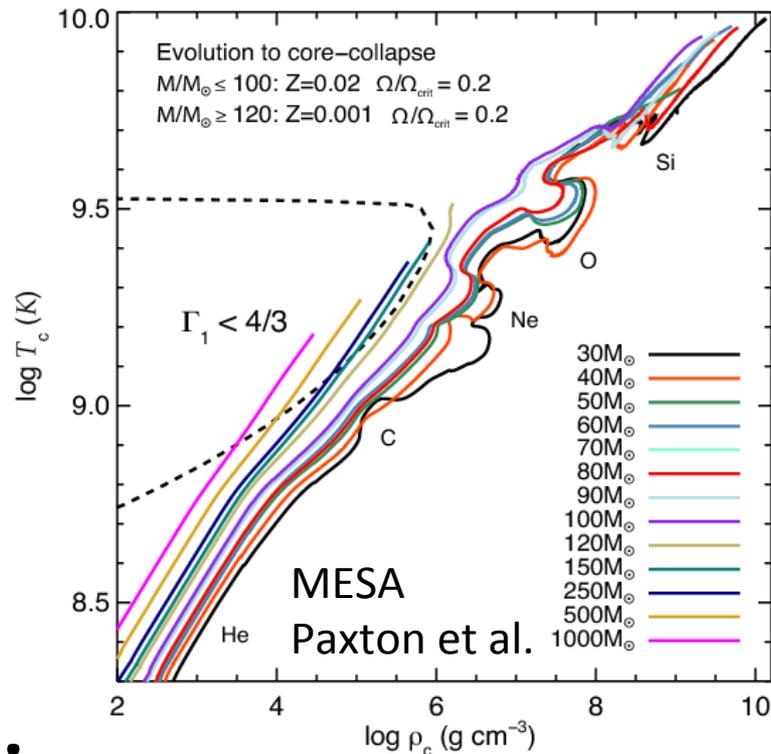


“Temperature” $E \text{ (MeV)} \sim kT_{10}$

Plasma
Gaseous
Fluid
Solid



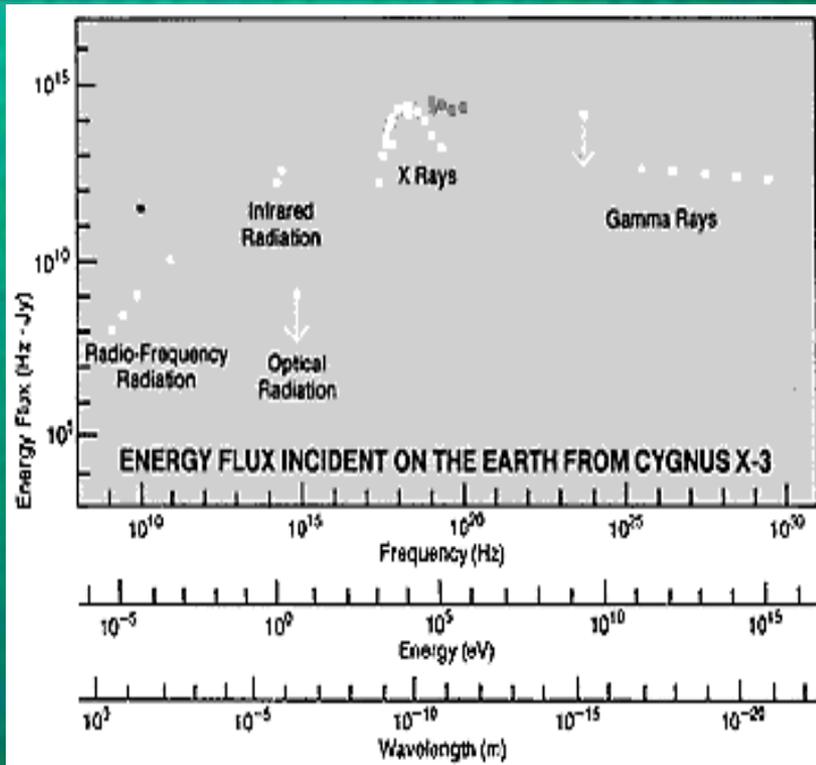
Physics at E-scale		T-scale
Particle	GeV	10^{13} K
Nuclear	MeV	10^{10} K
Atomic	keV	10^7 K
Atomic	eV	10^4 K
Molecular	meV	10 K



non-thermal MeV astrophysics
Nuclear Processes & Particle acceleration

Multiwavelength Astrophysics

Edited by France Córdova

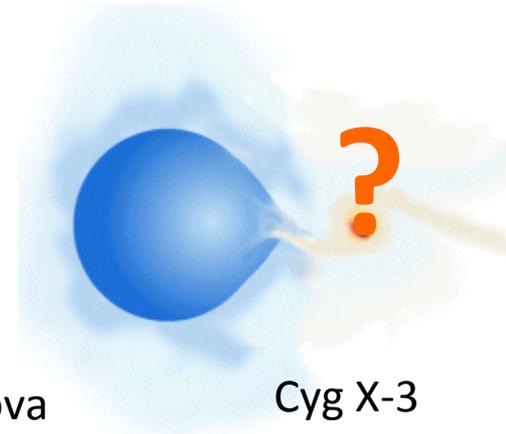


----> MeV Chauvinism is no good ☺

TDA: Time Domain Astrophysics

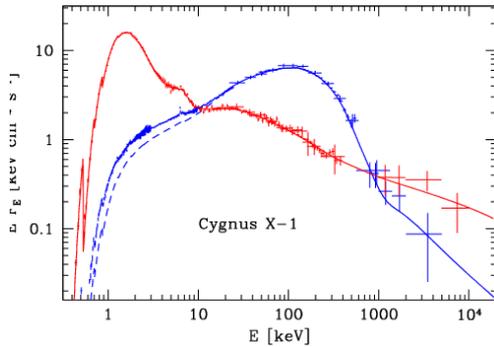
MMA: Multi-Messenger Astrophysics

All Sky Monitoring – Fast Response

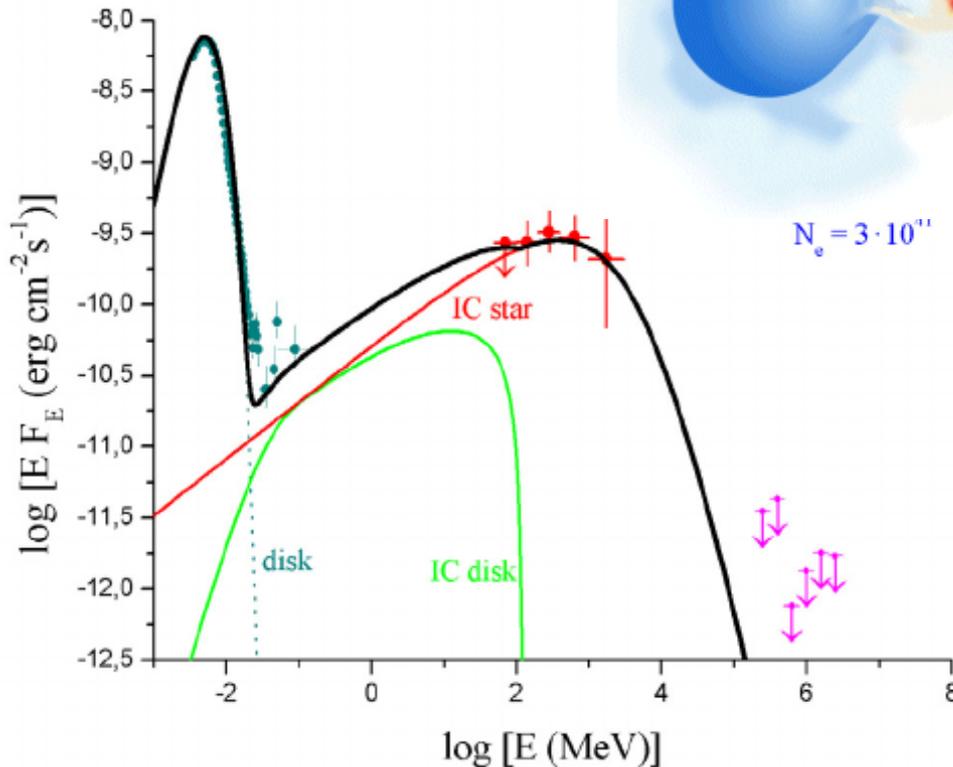
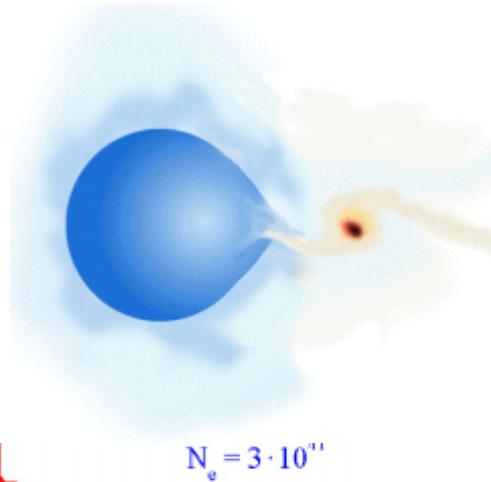


F. Cordova
workshop:
Taos, NM,
August 1987

Cyg X-3
Giacconi et al. 1967
50 years ago! -

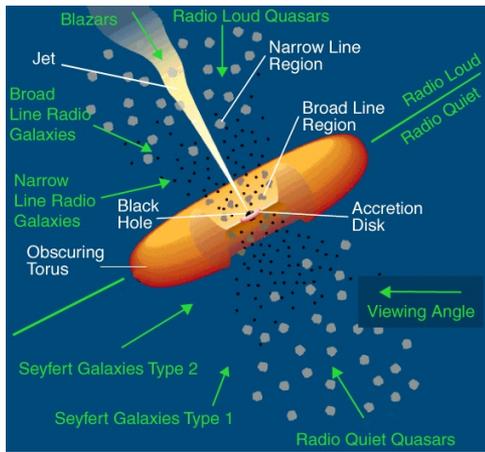


HMXRBs are characterized by two (or more) SED states which exhibit time variability on a variety of time scales



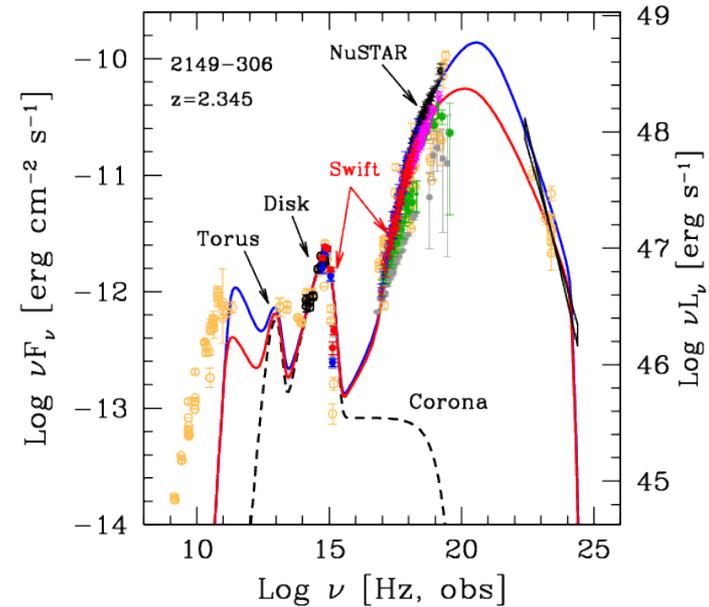
AGILE monitoring of Cyg X-3 (G. Piano, + 2012 A&A 545)
 SED during the main γ -ray events (non-sim. data) and the leptonic model. Blue: X-ray average "hypersoft" SED (Koljonen et al. 2010), RXTE-PCA and RXTE-HEXTE data (~ 3 to ~ 150 keV); red: AGILE-GRID (50 MeV to 3 GeV); magenta: MAGIC UL.

In Outburst ATel 11127: Piano+

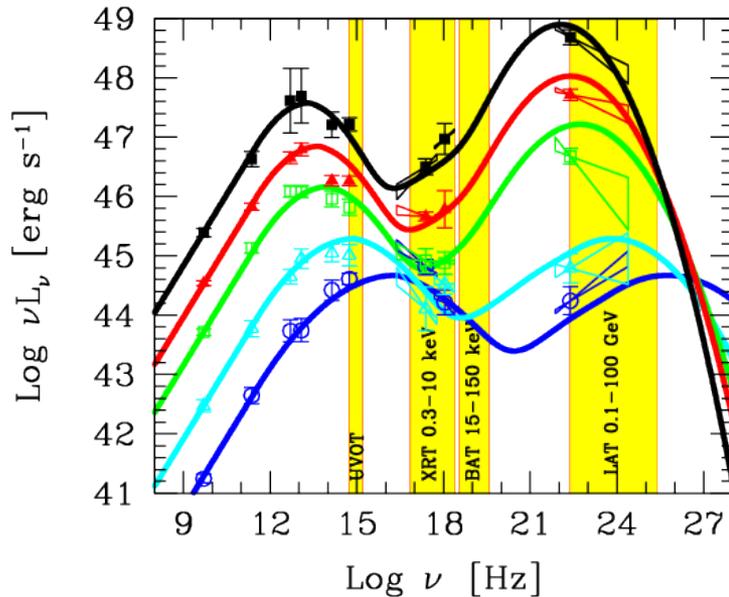


M. Urry and P. Padovani

PKS 2149--306, a blazar at $z=2.345$

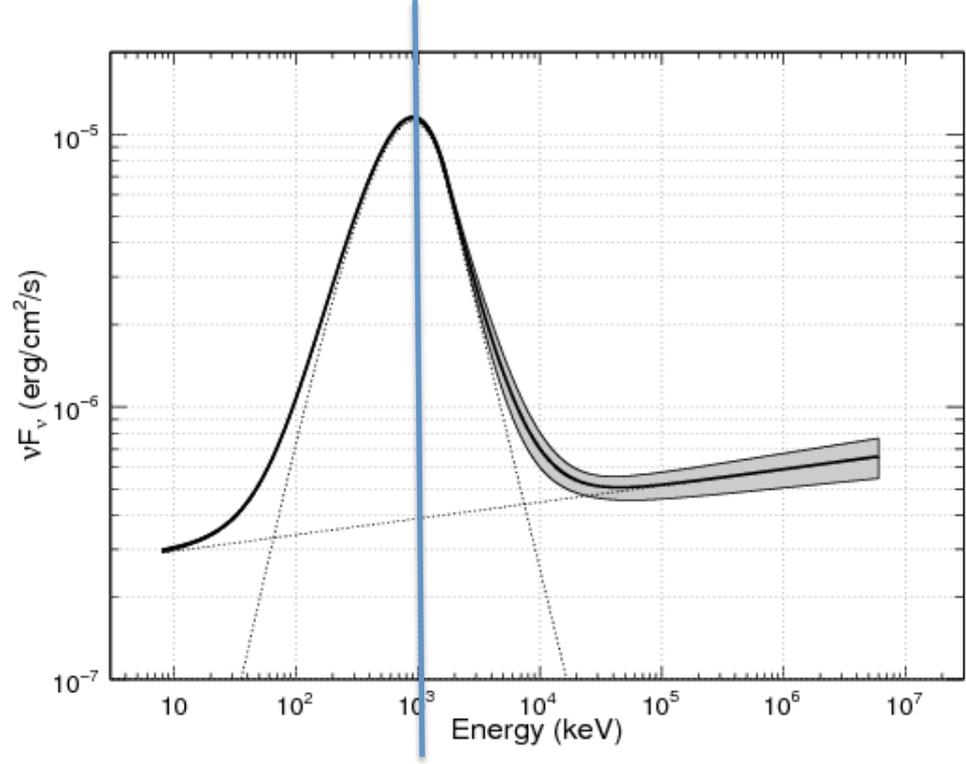


Blazar sequence: SEDs change according to $L_{\text{bol}}(\text{jet})$: Ghisellini+ 2015, JHEAp 7

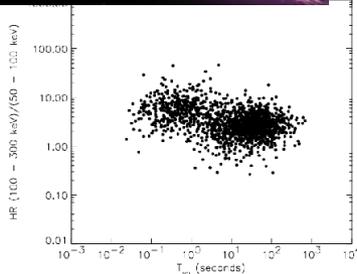


Tagliaferri et al 2015: Swift/XRT - NuSTAR, observing sim., 0.3--70 keV: Opt/UV bump due to the accretion disk, hard X-ray due to beamed jet emission (IC off photons produced by IR torus (hump at $\sim 10^{13}$ Hz)). **Archival data illustrate variability. Blazar power mostly around 1 MeV**, and are best found in hard X-ray surveys rather than >100 MeV surveys (of comparable $\nu F\nu$ sensitivities).

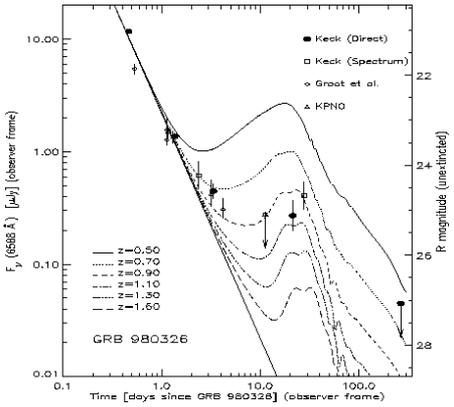
Long Duration GRBs



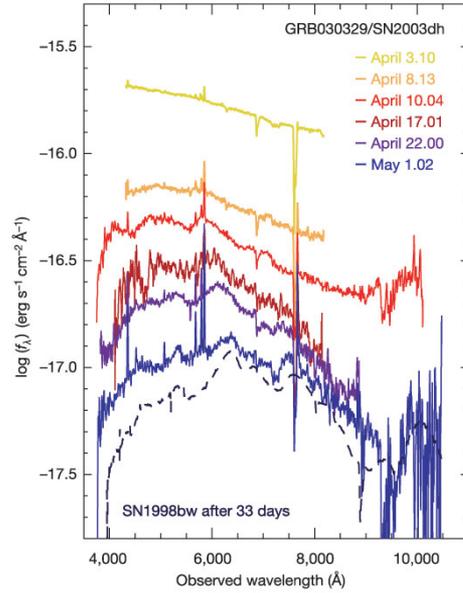
HR



Duration



GRB980326: Bloom+99



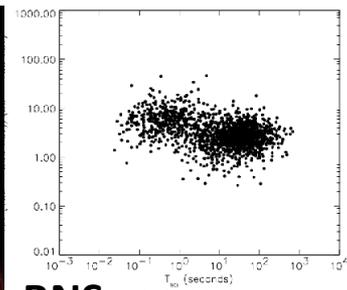
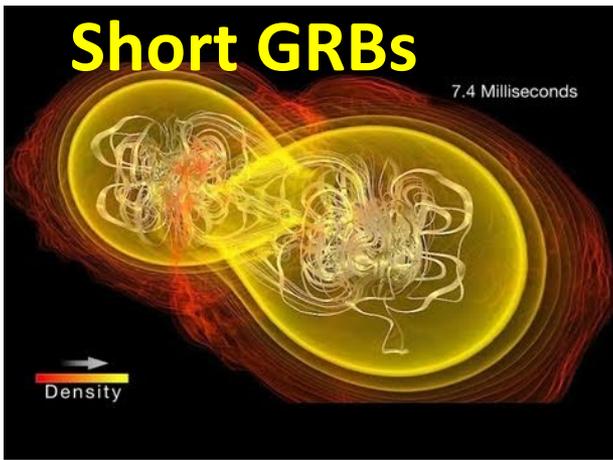
AG Spectroscopy: CCE



Stirling Colgate

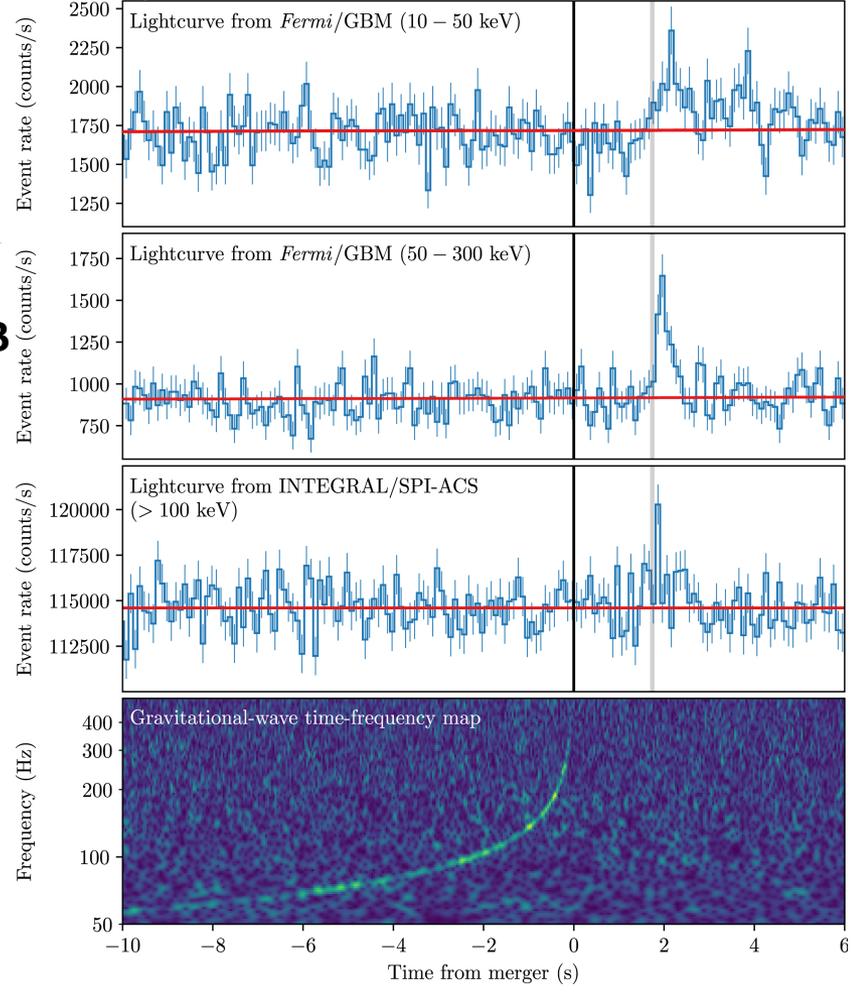
Atomic Heritage Foundation

1925 - 2013



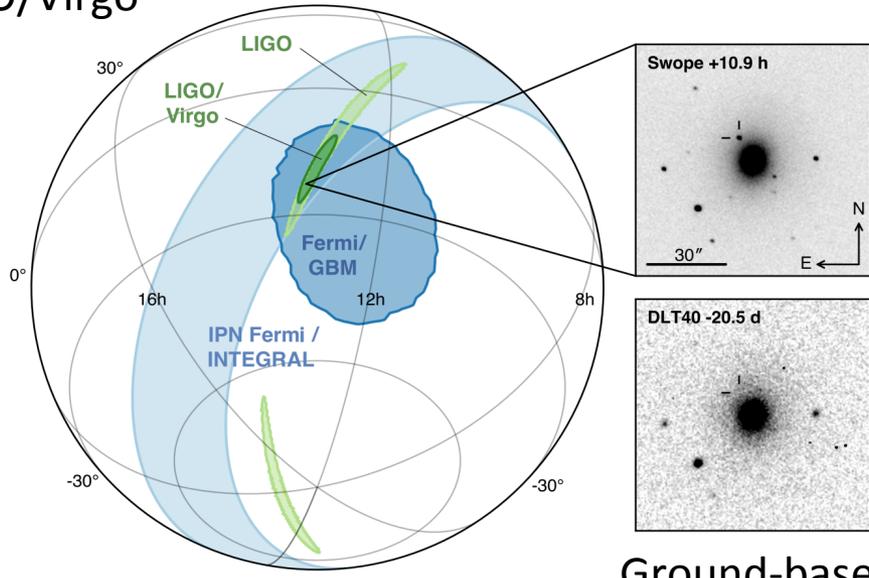
BNS merger
 -GW -short GRB
 - kilonova AG

Space-based ☺



GW170817/GRB170817A

LIGO/Virgo

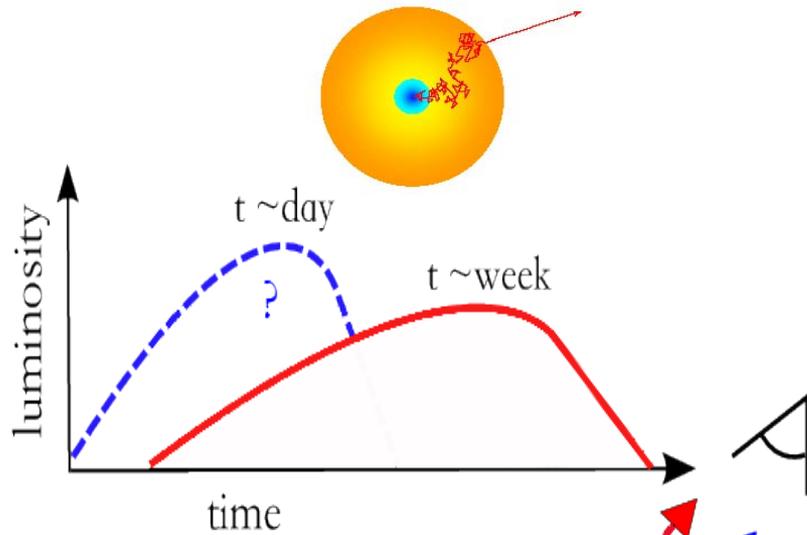


Ground-based ☺

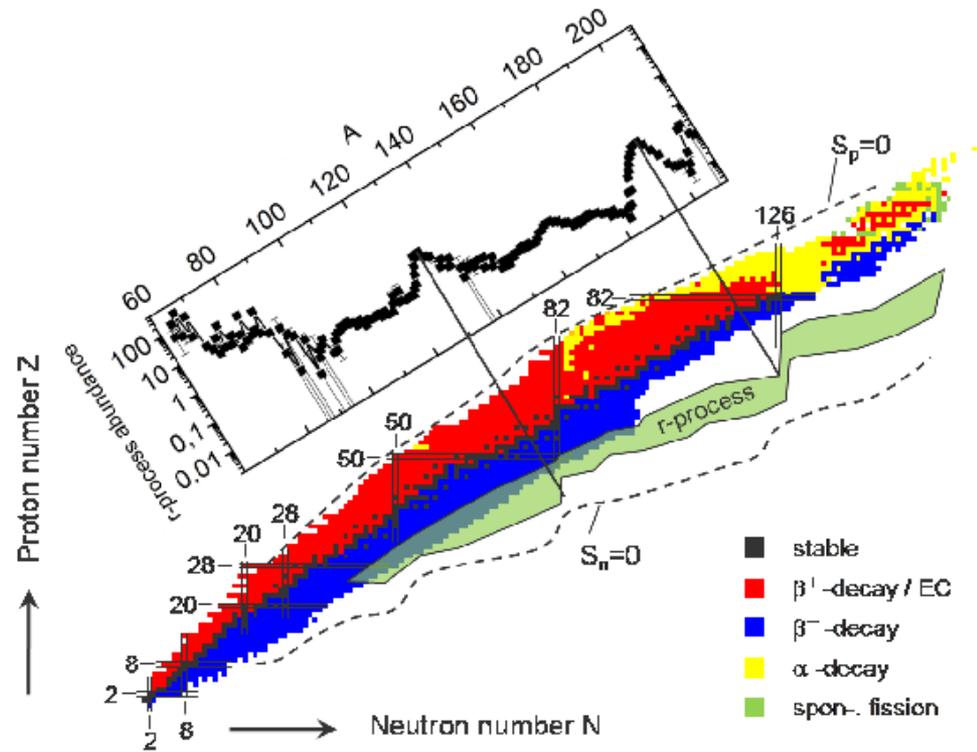
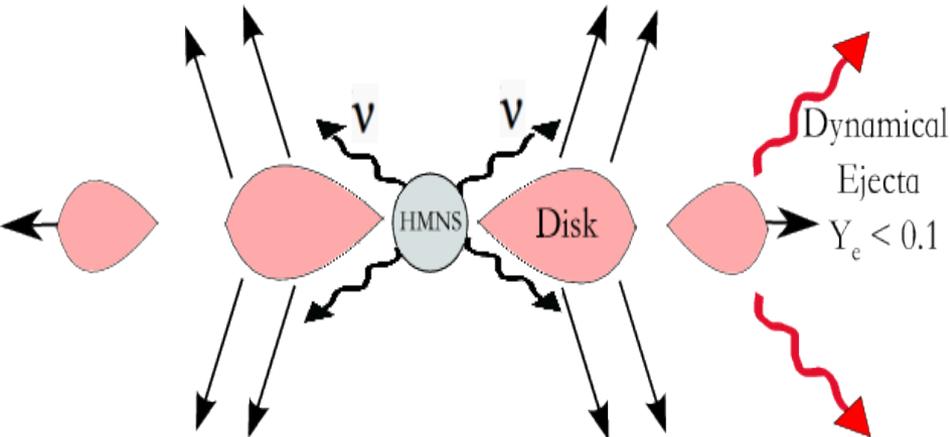
Abbott, B. P., et al. "Gravitational Waves and Gamma Rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A." 2017, *ApJL*, [848, L13](#).
 > 3,000 authors ☺

Underground-based: no detection ☹

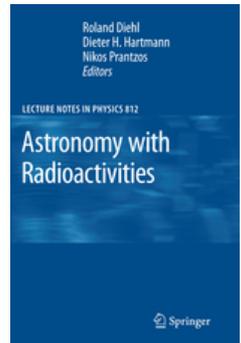
Kilo-Nova astrophysics



Disk Outflow
 $Y_e \sim 0.2 - 0.4$



A unique look at r-process
 nucleosynthesis in action



Nuclear Statistical Equilibrium (NSE)

- At $T > 0.5$ MeV, nuclear forward and backward reactions go into statistical equilibrium \rightarrow chemical equilibrium:

$$Z_i \mu_p + N_i \mu_n = \mu_i$$

nuclear species i

$$n = \sum_i n_i A_i$$

Mass conservation

$$n Y_e = n_p + 2n_\alpha + \sum_i Z_i n_i$$

Charge conservation

- Saha-like equations for abundances $Y_i = \frac{n_i}{n}$
nuclear part. fn.

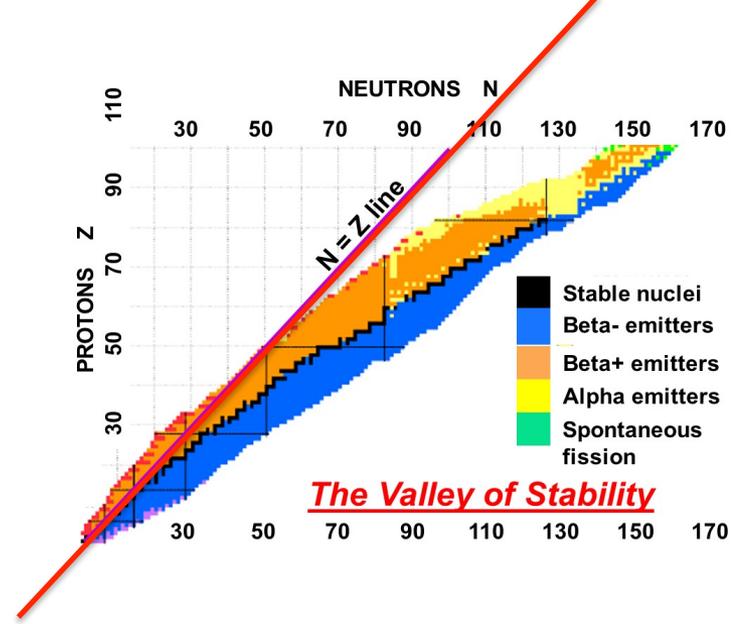
$$Y_{Z_i, A_i} = \frac{G_{Z_i, A_i}}{2^A (m_u kT / (2\pi\hbar))^2 (3/2[A-1])} (\rho N_A)^{A-1} Y_p^Z Y_n^N \exp\left(\frac{Q}{kT}\right)$$

$$Q = Zm_p + Nm_n - M(N, Z) \quad A = N + Z$$

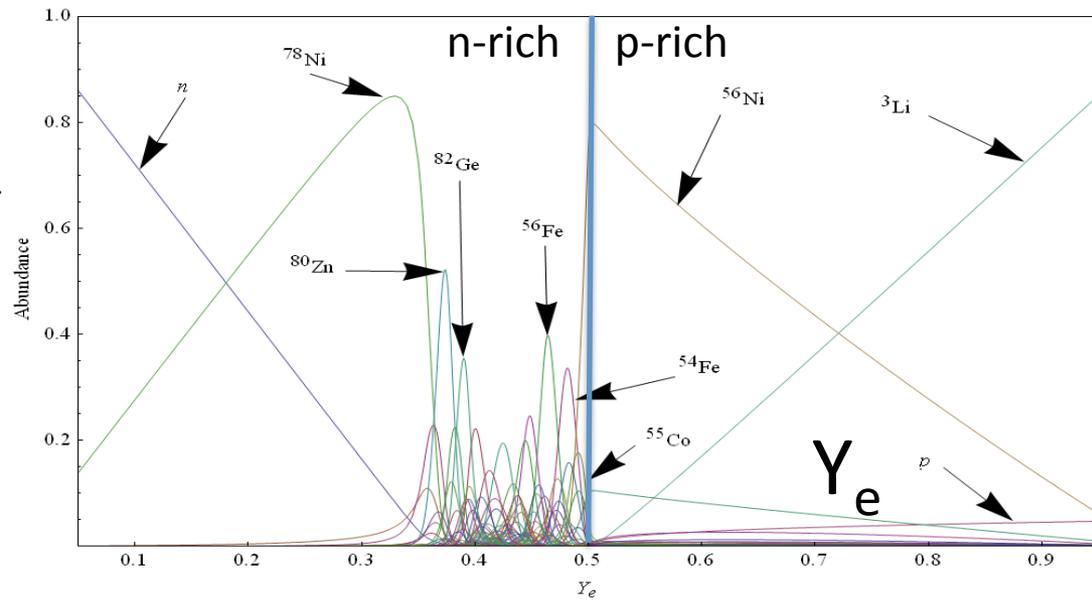
- Abundances completely determined by ρ, T, Y_e .

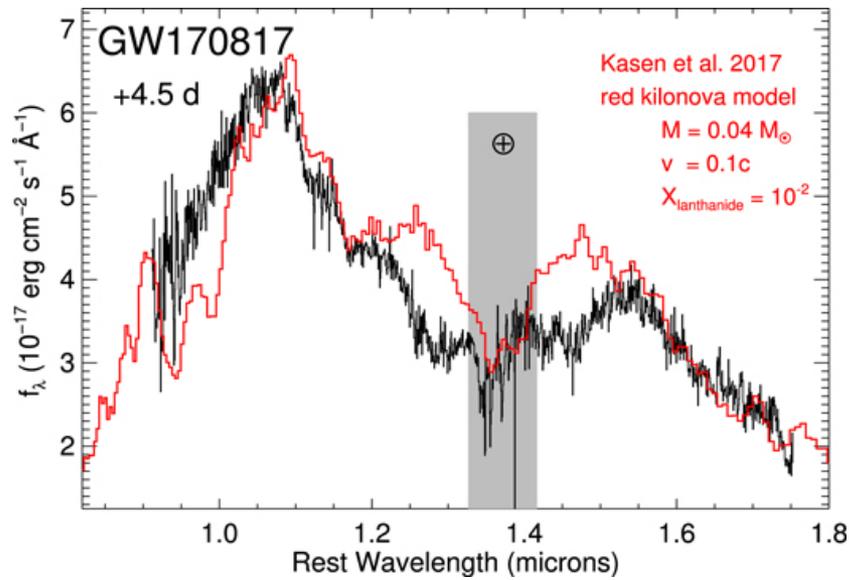
C. D. Ott @ YITPGW School, March 2015

$$Y_e(\text{Nd}) = Z/A = 60 / (60 + 60 + 22) \sim 0.4$$



$kT=0.5$ MeV, $\lg \rho=10$ [g/cm^3]

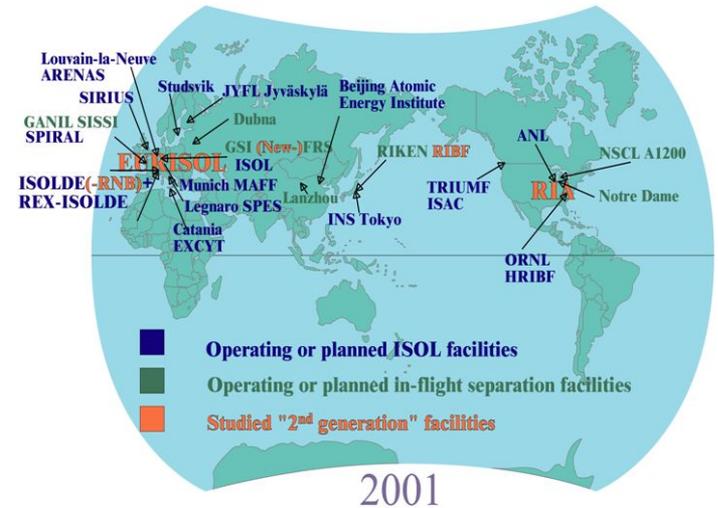




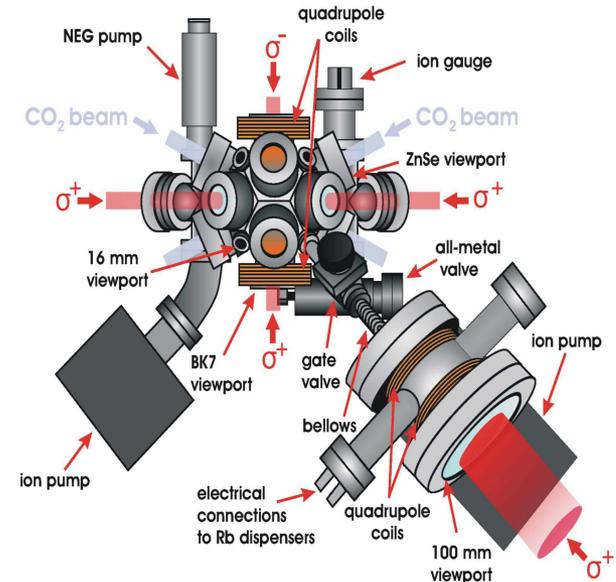
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1	H	1.008	2	He	4.003	3	Li	6.941	4	Be	9.012	5	B	10.81	6	C	12.01	7	N	14.01	8	O	16.00	9	F	18.998	10	Ne	20.18	11	Na	22.99	12	Mg	24.31	13	Al	26.98	14	Si	28.09	15	P	30.97	16	S	32.06	17	Cl	35.45	18	Ar	39.95	19	K	39.10	20	Ca	40.08	21	Sc	44.96	22	Ti	47.88	23	V	50.94	24	Cr	52.00	25	Mn	54.94	26	Fe	55.85	27	Co	58.93	28	Ni	58.70	29	Cu	63.55	30	Zn	65.38	31	Ga	69.72	32	Ge	72.64	33	As	74.92	34	Se	78.96	35	Br	79.90	36	Kr	83.80	37	Rb	85.47	38	Sr	87.62	39	Y	88.91	40	Zr	91.22	41	Nb	92.91	42	Mo	95.94	43	Tc	(98)	44	Ru	101.1	45	Rh	103.2	46	Pd	106.4	47	Ag	107.9	48	Cd	112.4	49	In	114.8	50	Sn	118.7	51	Sb	121.8	52	Te	127.6	53	I	126.9	54	Xe	131.3	55	Cs	132.9	56	Ba	137.3	57	La	138.9	58	Ce	140.1	59	Pr	140.9	60	Nd	144.2	61	Pm	(145)	62	Sm	150.4	63	Eu	151.9	64	Gd	157.3	65	Tb	158.9	66	Dy	162.5	67	Ho	164.9	68	Er	167.3	69	Tm	168.9	70	Yb	173.0	71	Lu	174.9	72	Hf	178.5	73	Ta	180.9	74	W	183.8	75	Re	186.2	76	Os	190.2	77	Ir	192.2	78	Pt	195.1	79	Au	197.0	80	Hg	200.6	81	Tl	204.4	82	Pb	207.2	83	Bi	209.0	84	Po	(209)	85	At	(210)	86	Rn	(222)	87	Fr	(223)	88	Ra	(226.0)	89	Ac	(227)	90	Th	(232)	91	Pa	(231)	92	U	(238.0)	93	Np	(237)	94	Pu	(244)	95	Am	(243)	96	Cm	(247)	97	Bk	(247)	98	Cf	(251)	99	Es	(252)	100	Fm	(257)	101	Md	(258)	102	No	(259)	103	Lr	(262)	104	Unk	(263)	105	Uns	(267)	106	Uue	(288)	107	Uub	(294)	108	Uuq	(304)	109	Uuq	(315)	110	Uuh	(329)	111	Uuq	(344)	112	Uuq	(348)	113	Uuq	(361)	114	Uuq	(370)	115	Uuq	(384)	116	Uuq	(393)	117	Uuq	(404)	118	Uuq	(414)	119	Uuq	(424)	120	Uuq	(434)	121	Uuq	(444)	122	Uuq	(454)	123	Uuq	(464)	124	Uuq	(474)	125	Uuq	(484)	126	Uuq	(494)	127	Uuq	(504)	128	Uuq	(514)	129	Uuq	(524)	130	Uuq	(534)	131	Uuq	(544)	132	Uuq	(554)	133	Uuq	(564)	134	Uuq	(574)	135	Uuq	(584)	136	Uuq	(594)	137	Uuq	(604)	138	Uuq	(614)	139	Uuq	(624)	140	Uuq	(634)	141	Uuq	(644)	142	Uuq	(654)	143	Uuq	(664)	144	Uuq	(674)	145	Uuq	(684)	146	Uuq	(694)	147	Uuq	(704)	148	Uuq	(714)	149	Uuq	(724)	150	Uuq	(734)	151	Uuq	(744)	152	Uuq	(754)	153	Uuq	(764)	154	Uuq	(774)	155	Uuq	(784)	156	Uuq	(794)	157	Uuq	(804)	158	Uuq	(814)	159	Uuq	(824)	160	Uuq	(834)	161	Uuq	(844)	162	Uuq	(854)	163	Uuq	(864)	164	Uuq	(874)	165	Uuq	(884)	166	Uuq	(894)	167	Uuq	(904)	168	Uuq	(914)	169	Uuq	(924)	170	Uuq	(934)	171	Uuq	(944)	172	Uuq	(954)	173	Uuq	(964)	174	Uuq	(974)	175	Uuq	(984)	176	Uuq	(994)	177	Uuq	(1004)	178	Uuq	(1014)	179	Uuq	(1024)	180	Uuq	(1034)	181	Uuq	(1044)	182	Uuq	(1054)	183	Uuq	(1064)	184	Uuq	(1074)	185	Uuq	(1084)	186	Uuq	(1094)	187	Uuq	(1104)	188	Uuq	(1114)	189	Uuq	(1124)	190	Uuq	(1134)	191	Uuq	(1144)	192	Uuq	(1154)	193	Uuq	(1164)	194	Uuq	(1174)	195	Uuq	(1184)	196	Uuq	(1194)	197	Uuq	(1204)	198	Uuq	(1214)	199	Uuq	(1224)	200	Uuq	(1234)	201	Uuq	(1244)	202	Uuq	(1254)	203	Uuq	(1264)	204	Uuq	(1274)	205	Uuq	(1284)	206	Uuq	(1294)	207	Uuq	(1304)	208	Uuq	(1314)	209	Uuq	(1324)	210	Uuq	(1334)	211	Uuq	(1344)	212	Uuq	(1354)	213	Uuq	(1364)	214	Uuq	(1374)	215	Uuq	(1384)	216	Uuq	(1394)	217	Uuq	(1404)	218	Uuq	(1414)	219	Uuq	(1424)	220	Uuq	(1434)	221	Uuq	(1444)	222	Uuq	(1454)	223	Uuq	(1464)	224	Uuq	(1474)	225	Uuq	(1484)	226	Uuq	(1494)	227	Uuq	(1504)	228	Uuq	(1514)	229	Uuq	(1524)	230	Uuq	(1534)	231	Uuq	(1544)	232	Uuq	(1554)	233	Uuq	(1564)	234	Uuq	(1574)	235	Uuq	(1584)	236	Uuq	(1594)	237	Uuq	(1604)	238	Uuq	(1614)	239	Uuq	(1624)	240	Uuq	(1634)	241	Uuq	(1644)	242	Uuq	(1654)	243	Uuq	(1664)	244	Uuq	(1674)	245	Uuq	(1684)	246	Uuq	(1694)	247	Uuq	(1704)	248	Uuq	(1714)	249	Uuq	(1724)	250	Uuq	(1734)	251	Uuq	(1744)	252	Uuq	(1754)	253	Uuq	(1764)	254	Uuq	(1774)	255	Uuq	(1784)	256	Uuq	(1794)	257	Uuq	(1804)	258	Uuq	(1814)	259	Uuq	(1824)	260	Uuq	(1834)	261	Uuq	(1844)	262	Uuq	(1854)	263	Uuq	(1864)	264	Uuq	(1874)	265	Uuq	(1884)	266	Uuq	(1894)	267	Uuq	(1904)	268	Uuq	(1914)	269	Uuq	(1924)	270	Uuq	(1934)	271	Uuq	(1944)	272	Uuq	(1954)	273	Uuq	(1964)	274	Uuq	(1974)	275	Uuq	(1984)	276	Uuq	(1994)	277	Uuq	(2004)	278	Uuq	(2014)	279	Uuq	(2024)	280	Uuq	(2034)	281	Uuq	(2044)	282	Uuq	(2054)	283	Uuq	(2064)	284	Uuq	(2074)	285	Uuq	(2084)	286	Uuq	(2094)	287	Uuq	(2104)	288	Uuq	(2114)	289	Uuq	(2124)	290	Uuq	(2134)	291	Uuq	(2144)	292	Uuq	(2154)	293	Uuq	(2164)	294	Uuq	(2174)	295	Uuq	(2184)	296	Uuq	(2194)	297	Uuq	(2204)	298	Uuq	(2214)	299	Uuq	(2224)	300	Uuq	(2234)	301	Uuq	(2244)	302	Uuq	(2254)	303	Uuq	(2264)	304	Uuq	(2274)	305	Uuq	(2284)	306	Uuq	(2294)	307	Uuq	(2304)	308	Uuq	(2314)	309	Uuq	(2324)	310	Uuq	(2334)	311	Uuq	(2344)	312	Uuq	(2354)	313	Uuq	(2364)	314	Uuq	(2374)	315	Uuq	(2384)	316	Uuq	(2394)	317	Uuq	(2404)	318	Uuq	(2414)	319	Uuq	(2424)	320	Uuq	(2434)	321	Uuq	(2444)	322	Uuq	(2454)	323	Uuq	(2464)	324	Uuq	(2474)	325	Uuq	(2484)	326	Uuq	(2494)	327	Uuq	(2504)	328	Uuq	(2514)	329	Uuq	(2524)	330	Uuq	(2534)	331	Uuq	(2544)	332	Uuq	(2554)	333	Uuq	(2564)	334	Uuq	(2574)	335	Uuq	(2584)	336	Uuq	(2594)	337	Uuq	(2604)	338	Uuq	(2614)	339	Uuq	(2624)	340	Uuq	(2634)	341	Uuq	(2644)	342	Uuq	(2654)	343	Uuq	(2664)	344	Uuq	(2674)	345	Uuq	(2684)	346	Uuq	(2694)	347	Uuq	(2704)	348	Uuq	(2714)	349	Uuq	(2724)	350	Uuq	(2734)	351	Uuq	(2744)	352	Uuq	(2754)	353	Uuq	(2764)	354	Uuq	(2774)	355	Uuq	(2784)	356	Uuq	(2794)	357	Uuq	(2804)	358	Uuq	(2814)	359	Uuq	(2824)	360	Uuq	(2834)	361	Uuq	(2844)	362	Uuq	(2854)	363	Uuq	(2864)	364	Uuq	(2874)	365	Uuq	(2884)	366	Uuq	(2894)	367	Uuq	(2904)	368	Uuq	(2914)	369	Uuq	(2924)	370	Uuq	(2934)	371	Uuq	(2944)	372	Uuq	(2954)	373	Uuq	(2964)	374	Uuq	(2974)	375	Uuq	(2984)	376	Uuq	(2994)	377	Uuq	(3004)	378	Uuq	(3014)	379	Uuq	(3024)	380	Uuq	(3034)	381	Uuq	(3044)	382	Uuq	(3054)	383	Uuq	(3064)	384	Uuq	(3074)	385	Uuq	(3084)	386	Uuq	(3094)	387	Uuq	(3104)	388	Uuq	(3114)	389	Uuq	(3124)	390	Uuq	(3134)	391	Uuq	(3144)	392	Uuq	(3154)	393	Uuq	(3164)	394	Uuq	(3174)	395	Uuq	(3184)	396	Uuq	(3194)	397	Uuq	(3204)	398	Uuq	(3214)	399	Uuq	(3224)	400	Uuq	(3234)	401	Uuq	(3244)	402	Uuq	(3254)	403	Uuq	(3264)	404	Uuq	(3274)	405	Uuq	(3284)	406	Uuq	(3294)	407	Uuq	(3304)	408	Uuq	(3314)	409	Uuq	(3324)	410	Uuq	(3334)	411	Uuq	(3344)	412	Uuq	(3354)	413	Uuq	(3364)	414	Uuq	(3374)	415	Uuq	(3384)	416	Uuq	(3394)	417	Uuq	(3404)	418	Uuq	(3414)	419	Uuq	(3424)	420	Uuq	(3434)	421	Uuq	(3444)	422	Uuq	(3454)	423	Uuq	(3464)	424	Uuq	(3474)	425	Uuq	(3484)	426	Uuq	(3494)	427	Uuq	(3504)	428	Uuq	(3514)	429	Uuq	(3524)	430	Uuq	(3534)	431	Uuq	(3544)	432	Uuq	(3554)	433	Uuq	(3564)	434	Uuq	(3574)	435	Uuq	(3584)	436	Uuq	(3594)	437	Uuq	(3604)	438	Uuq	(3614)	439	Uuq	(3624)	440	Uuq	(3634)	441	Uuq	(3644)	442	Uuq	(3654)	443	Uuq	(3664)	444	Uuq	(3674)	445	Uuq	(3684)	446	Uuq	(3694)	447	Uuq	(3704)	448	Uuq	(3714)	449	Uuq	(3724)	450	Uuq	(3734)	451	Uuq	(3744)	452	Uuq	(3754)	453	Uuq	(3764)	454	Uuq	(3774)	455	Uuq	(3784)	456	Uuq	(3794)	457	Uuq	(3804)	458	Uuq	(3814)	459	Uuq	(3824)	460	Uuq	(3834)	461	Uuq	(3844)	462	Uuq	(3854)	463	Uuq	(3864)	464	Uuq	(3874)	465	Uuq	(3884)	466	Uuq	(3894)	467	Uuq	(3904)	468	Uuq	(3914)	469	Uuq	(3924)	470	Uuq	(3934)	471	Uuq	(3944)	472	Uuq	(3954)	473	Uuq	(3964)	474	Uuq	(3974)	475	Uuq	(3984)	476	Uuq	(3994)	477	Uuq	(4004)	478	Uuq	(4014)	479	Uuq	(4024)	480	Uuq	(4034)	481	Uuq	(4044)	482	Uuq	(4054)	483	Uuq	(4064)	484	Uuq	(4074)	485	Uuq	(4084)	486	Uuq	(4094)	487	Uuq	(4104)	488	Uuq	(4114)	489	Uuq	(4124)	490	Uuq	(4134)	491	Uuq	(4144)	492	Uuq	(4154)	493	Uuq	(4164)

Nucleosynthesis studies need input from
Lab Astro: nuclear masses, lifetimes, etc.:

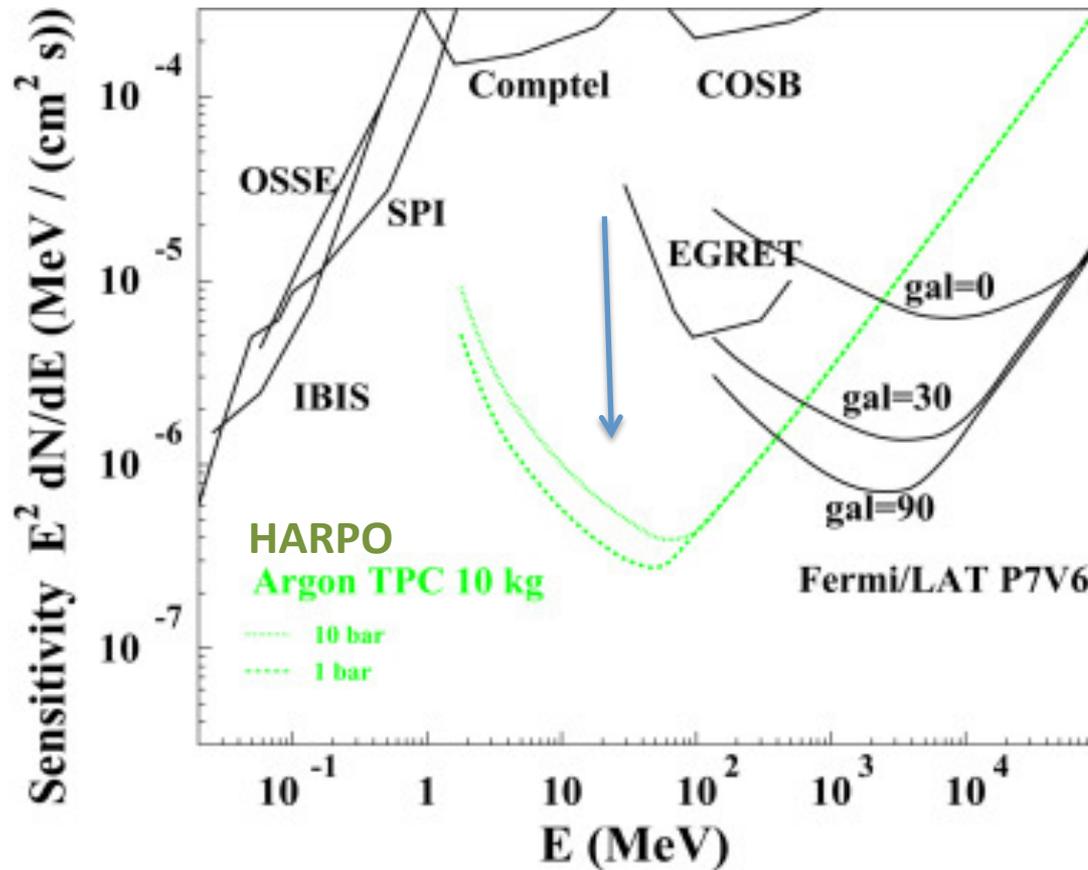
World Wide Radioactive Beam Facilities



Full use of kN spectroscopy requires input from
Lab Astro: EBITs etc



We have an MeV sensitivity gap



Y. Geerenbaert, et al 2017, NIM 845

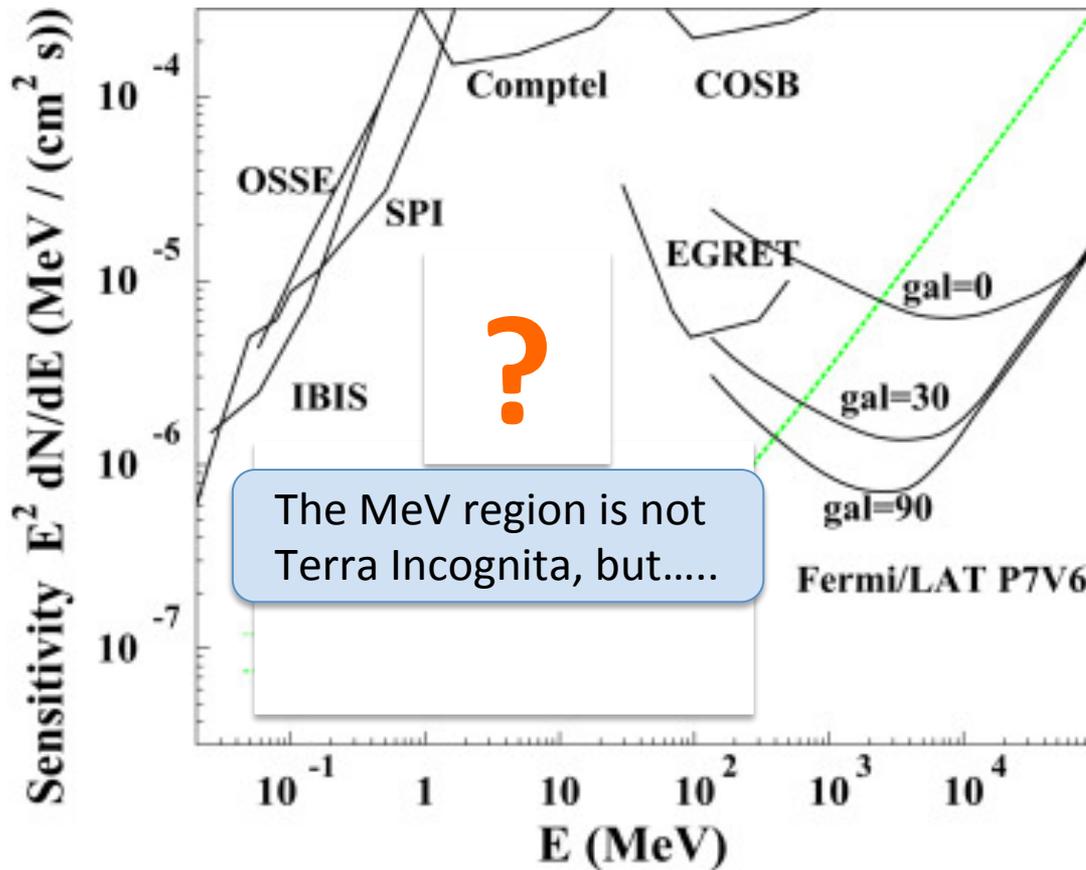
How to close the gap?

Larger Detectors
Smarter Event Analysis
Novel Concepts

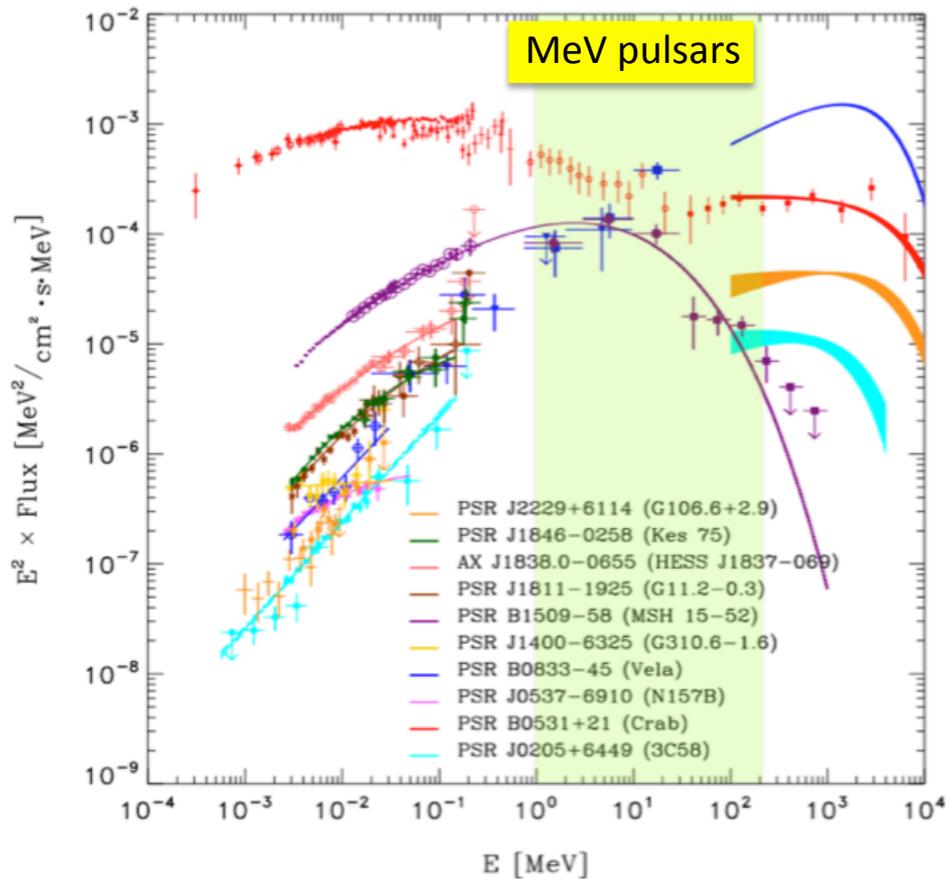
See Talks on
eASTROGAM
AMEGO
TAO/TAP
COSI-X
LOX

... we have many ideas,
and \$/photon is high, so
let us explore further
why the MeV band is so
important.

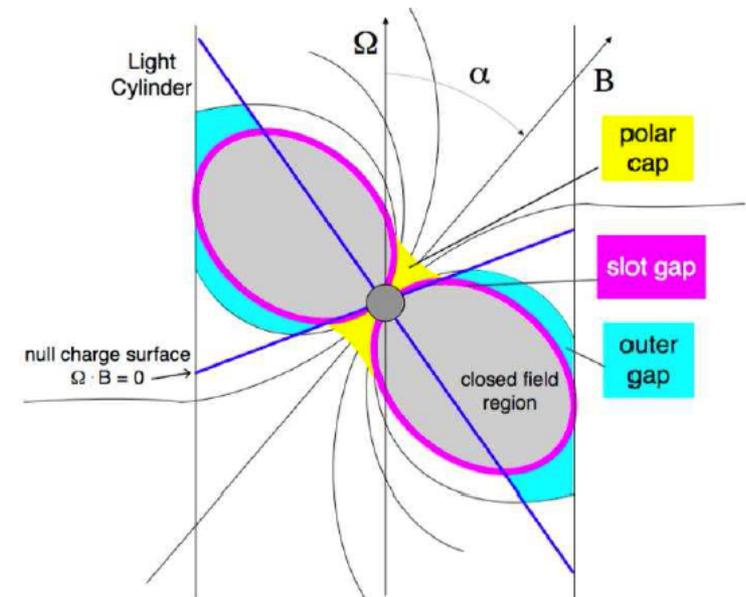
The MeV discovery land



...it a) contains many sources whose power peaks there, and, b) it probes unique aspects of nuclear astrophysics



- * Pulsars seen in hard X-ray but not by Fermi-LAT, peak in MeV band
- * 11 MeV pulsars known
 - Extreme $E_{\text{dot}} > 10^{36}$ erg
 - Possible “hidden” population of energetic soft gamma-ray pulsars
 - Emission might probe different part of the magnetosphere than GeV



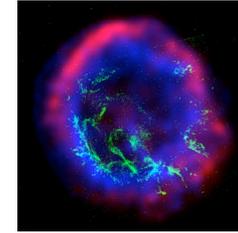
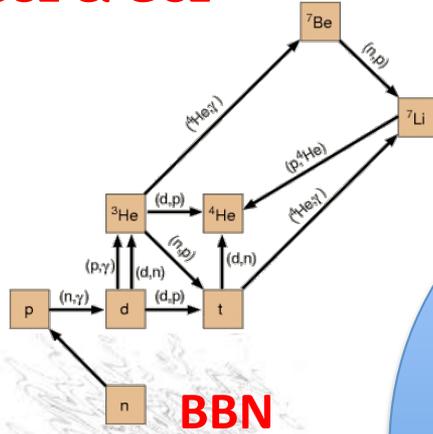
Puzzles:

- Why do most have single peaked lightcurves?
- Why are most are radio quiet?
- Why do their SEDs peak near MeV ?

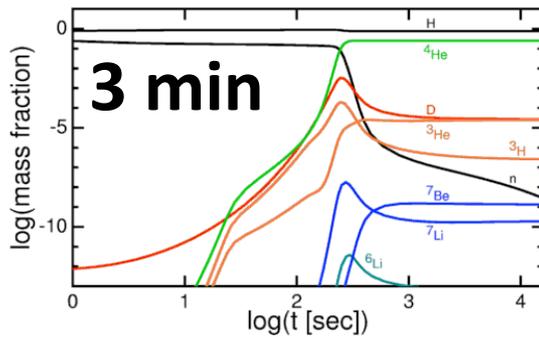
**Chemical Evolution
Element Synthesis
CCE & GCE**



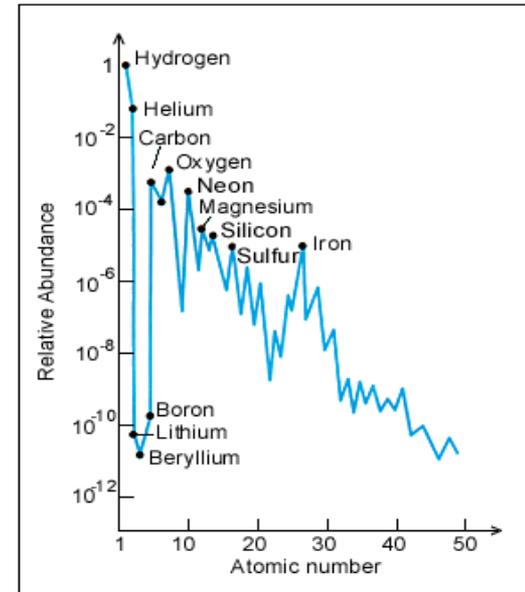
**Production (stars, CR spallation)
& Redistribution SN-SNR-ISM
Star Formation History & IMF**



13.4 Gyrs later
 $z_{\text{ISM}} \sim 2\%$



Multi-Messenger:
☉, Stellar atmospheres
ISM gas abundances
Meteorites
Radioactivities, γ -lines



The players:

Sources

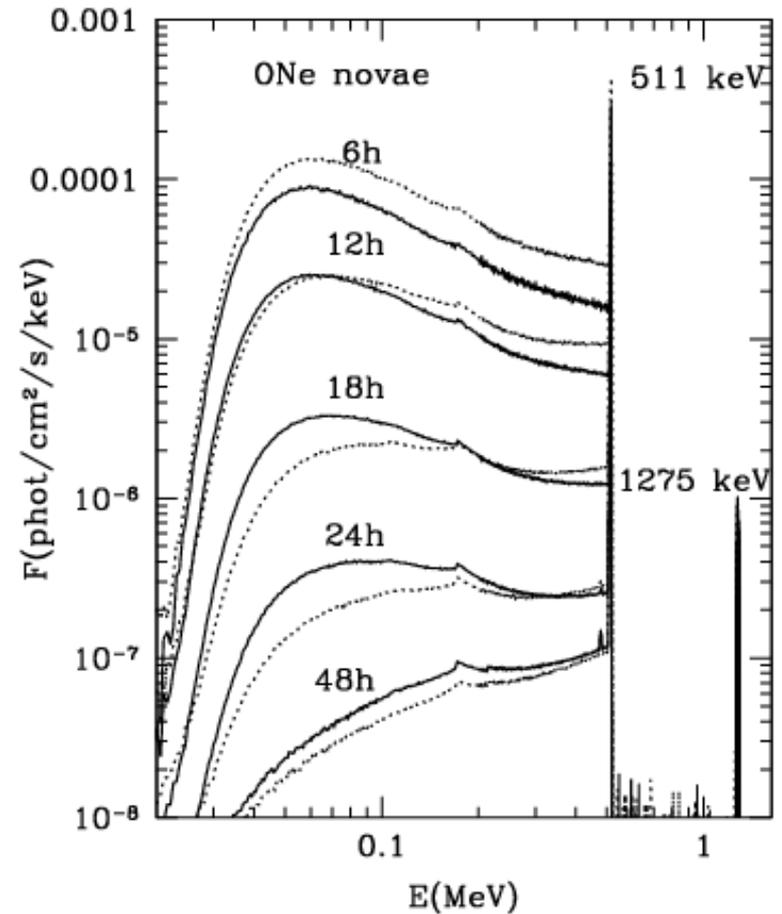
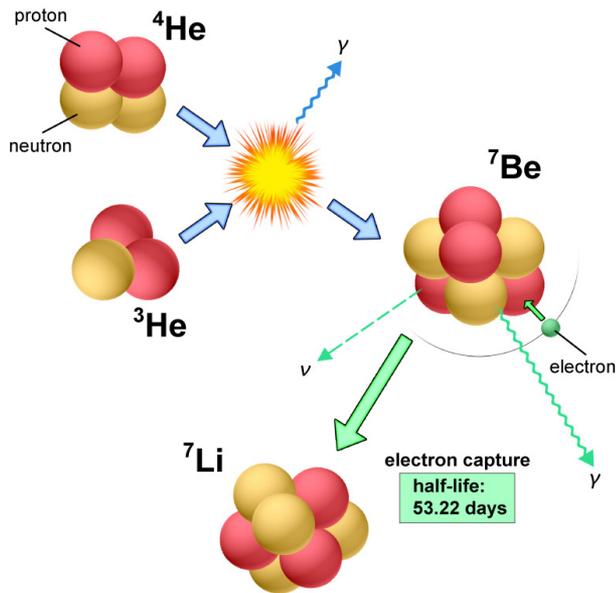
Isotope	Mean Lifetime	Decay Chain	γ -Ray Energy (keV)
${}^7\text{Be}$	77 d	${}^7\text{Be} \rightarrow {}^7\text{Li}^*$	478
${}^{56}\text{Ni}$	111 d	${}^{56}\text{Ni} \rightarrow {}^{56}\text{Co}^* \rightarrow {}^{56}\text{Fe}^* + e^+$	158, 812; 847, 1238
${}^{57}\text{Ni}$	390 d	${}^{57}\text{Co} \rightarrow {}^{57}\text{Fe}^*$	122
${}^{22}\text{Na}$	3.8 y	${}^{22}\text{Na} \rightarrow {}^{22}\text{Ne}^* + e^+$	1275
${}^{44}\text{Ti}$	89 y	${}^{44}\text{Ti} \rightarrow {}^{44}\text{Sc}^* \rightarrow {}^{44}\text{Ca}^* + e^+$	78, 68; 1157
${}^{26}\text{Al}$	$1.04 \cdot 10^6 \text{y}$	${}^{26}\text{Al} \rightarrow {}^{26}\text{Mg}^* + e^+$	1809
${}^{60}\text{Fe}$	$2.0 \cdot 10^6 \text{y}$	${}^{60}\text{Fe} \rightarrow {}^{60}\text{Co}^* \rightarrow {}^{60}\text{Ni}^*$	59, 1173, 1332
e^+	$\dots \cdot 10^5 \text{y}$	$e^+ + e^- \rightarrow \text{Ps} \rightarrow \gamma\gamma..$	511, <511

Diffuse

Key: $(M_{\text{ej}}/\tau) R_{\text{event}} F_{\text{escape}}$

Novae: not yet detected
In the MeV regime:

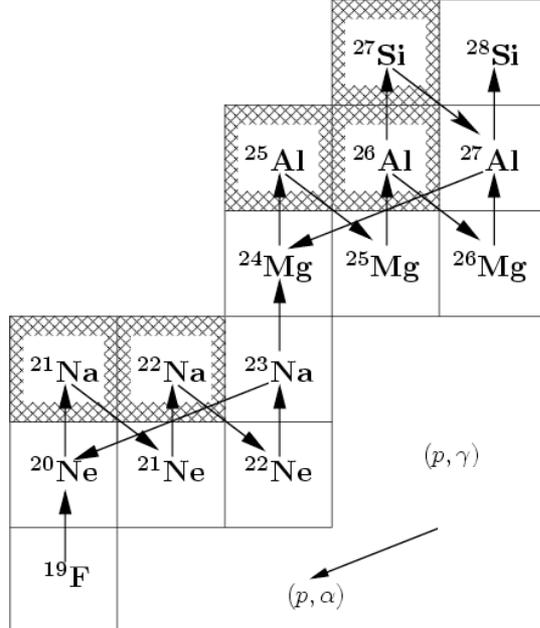
While Fermi established novae as GeV sources



Hernanz 2012

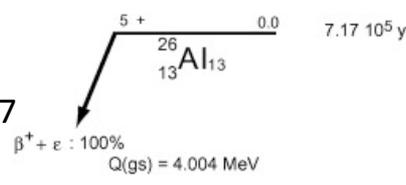
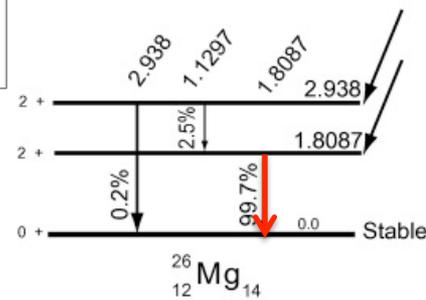
Galactic Rate ~ 40 / yr : Deep monitoring with Next-Gen Instrument could change this situation

We would learn about their dynamic envelope expansion



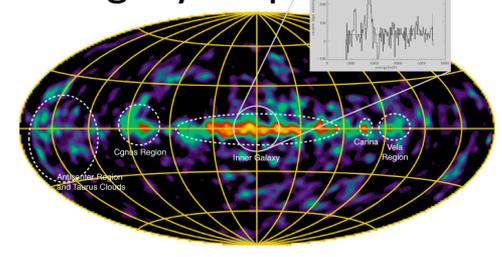
^{26}Al

Ramaty & Lingenfelter 77
HEAO-3 Mahoney+ 82



$I\beta^+$	$I\epsilon$
81.7%	2.7%
15.5%	15.5%

COMPTEL/CGRO legacy map



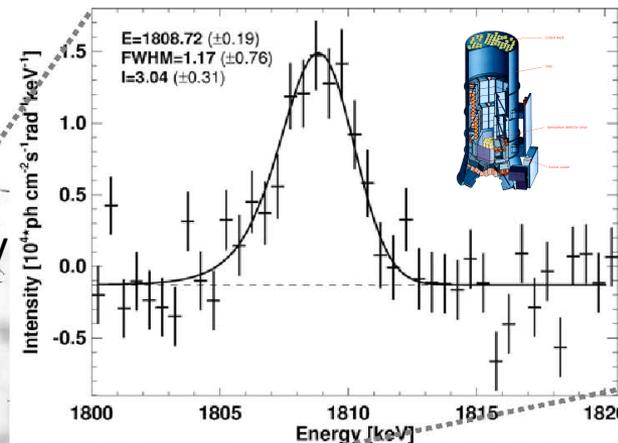
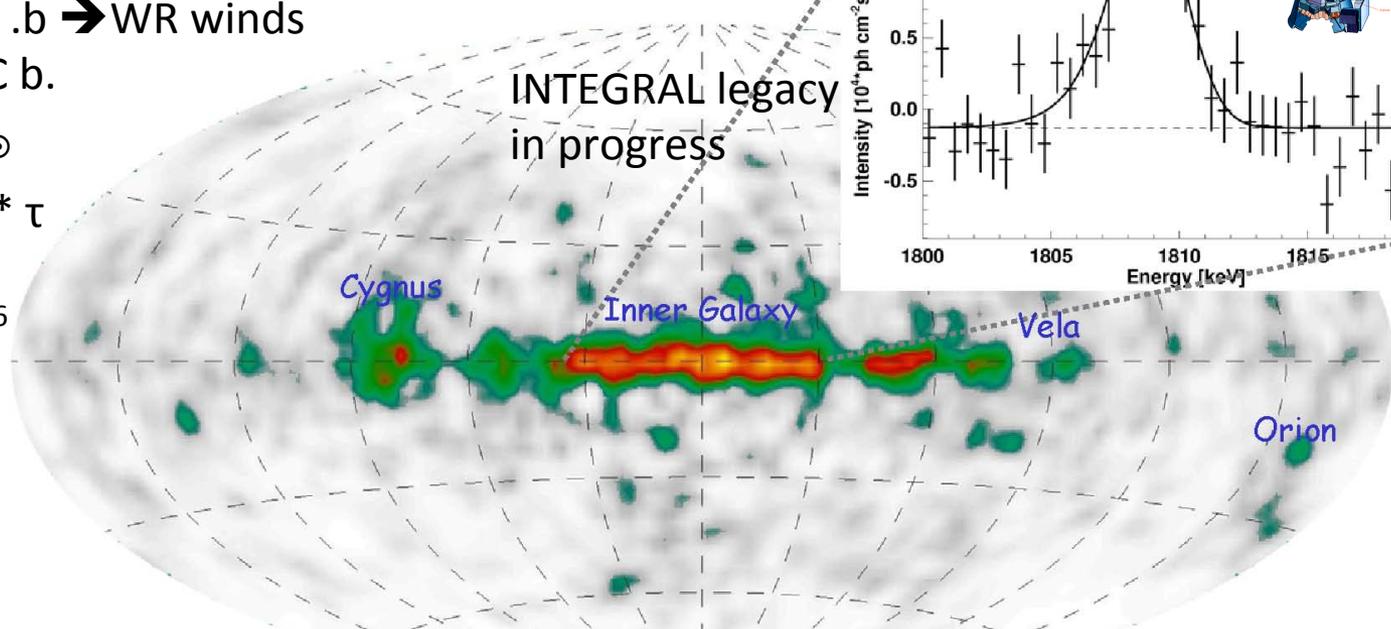
Static H/He-shell .b \rightarrow WR winds
& explosive Ne/C b.
<Yield> $\sim 10^{-4} M_{\odot}$

$$M_{\text{ISM}} = \text{SNR} * M_{\text{ej}} * \tau$$

$$\sim 10^{-2} 10^{-4} M_{\odot} 10^6$$



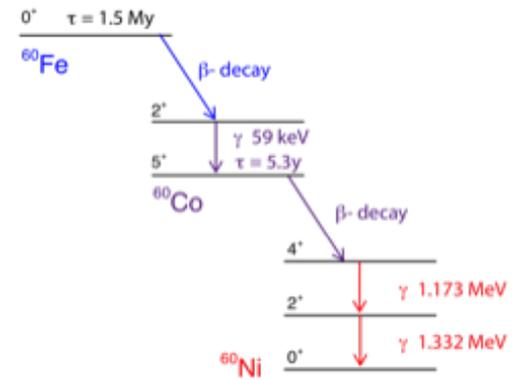
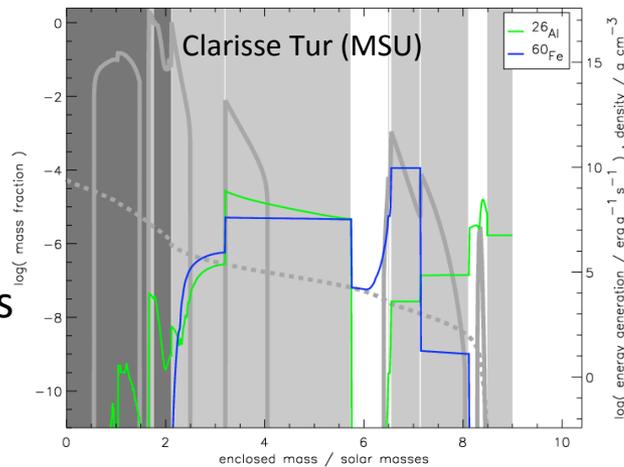
INTEGRAL legacy in progress



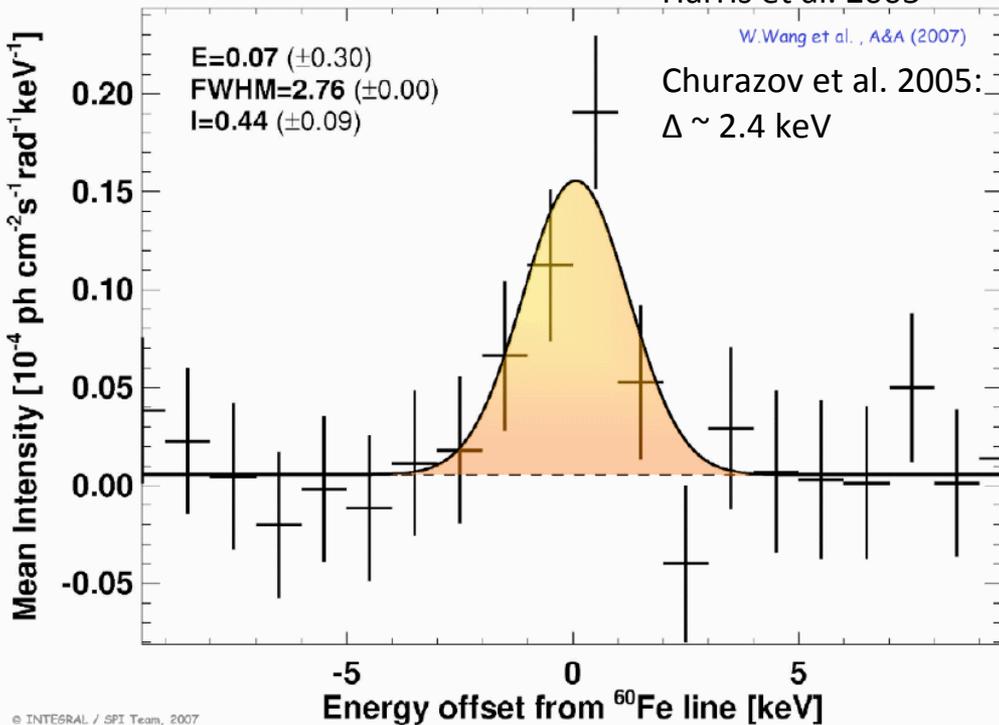
The Global galactic SFR $\sim 2-3 M_{\odot} \text{ yr}^{-1}$

^{26}Al & ^{60}Fe

Coproduced in massive stars:
Static He-shell burning s-process
(the explosion only ejects!)



RHESSI: Smith 2005
INTEGRAL/SPI
Harris et al. 2005



Rate uncertainties

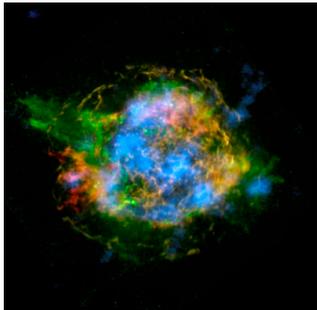
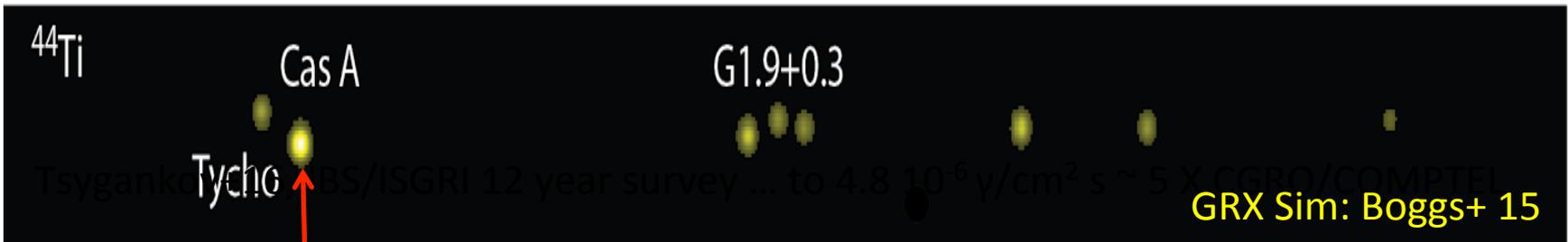
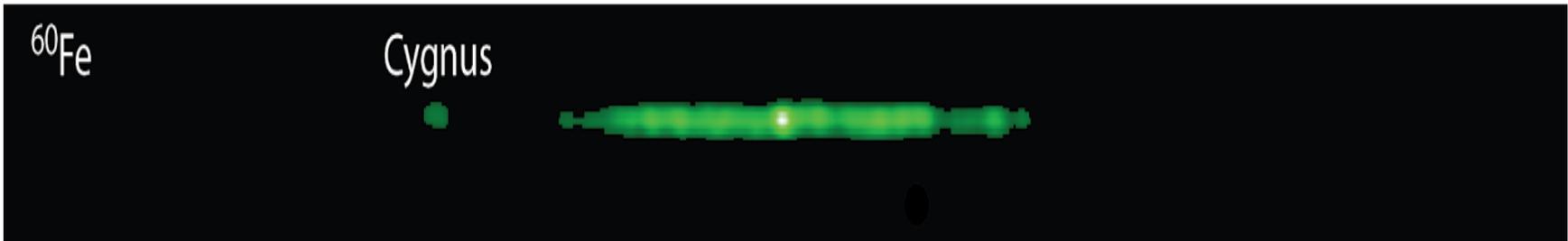
→ yield uncertainties

Mass loss

$^{26}\text{Al}/^{60}\text{Fe}$ flux ratio

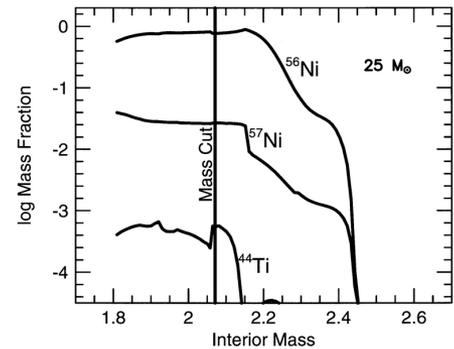
~ 10-20% ✓

For SNII/Nova decomposition
We need a map



✓ But no other

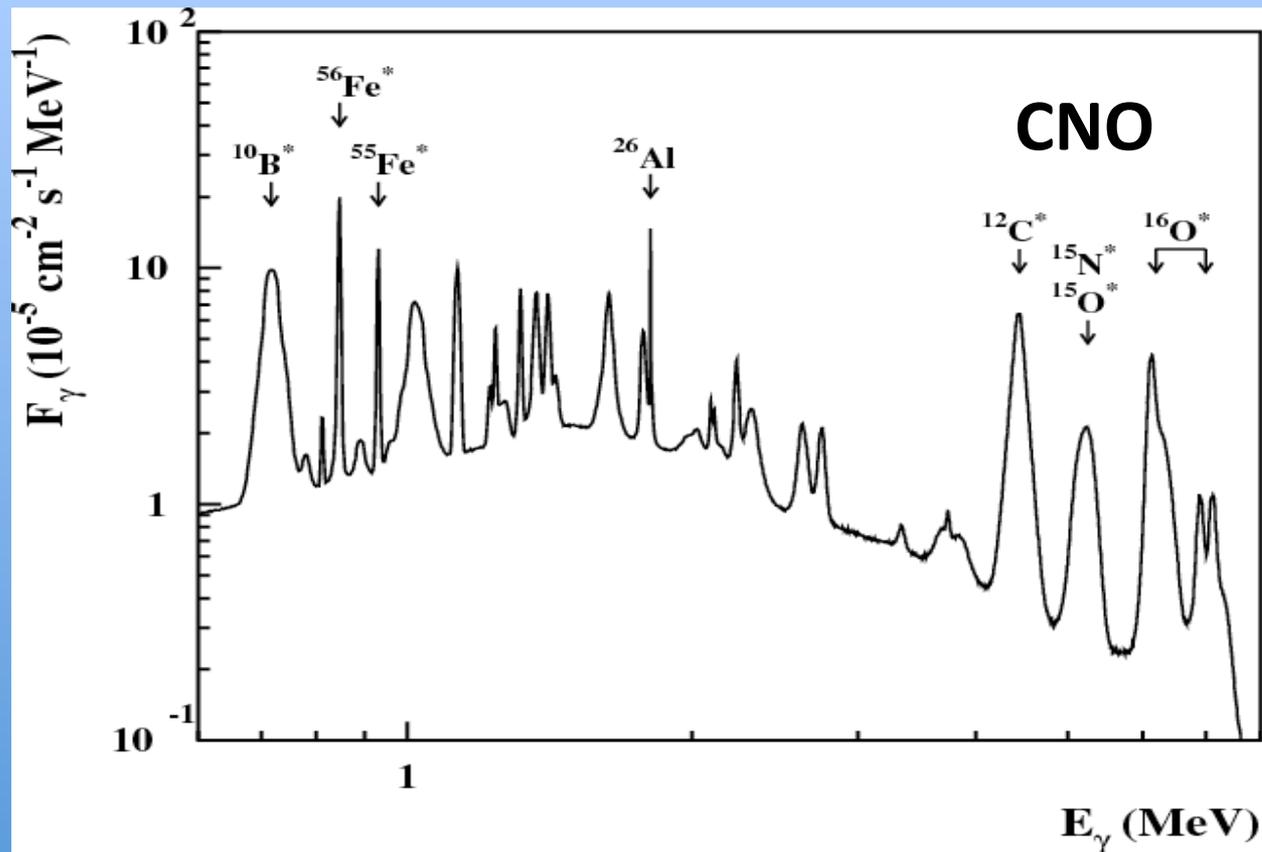
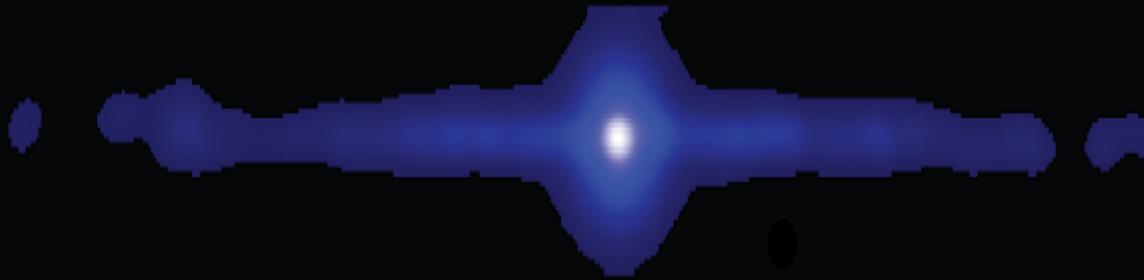
The $Y_{44} (1/4\pi D^2) \exp(-t/\tau)$ challenge for sensitivity



L.-S. The et al. 06: ^{44}Ti sources are rare events

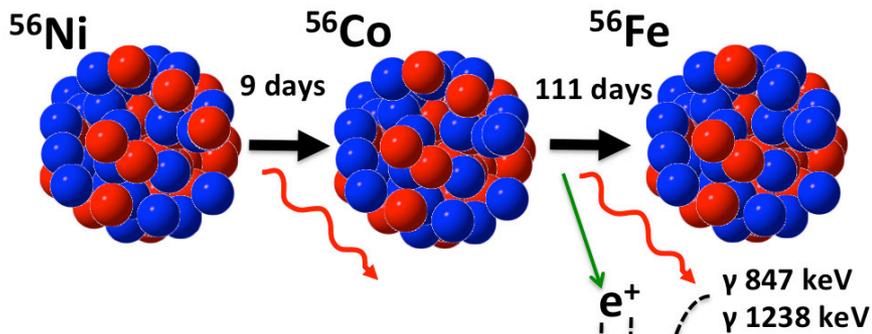
The Galactic positron distribution remains largely unexplored

positrons

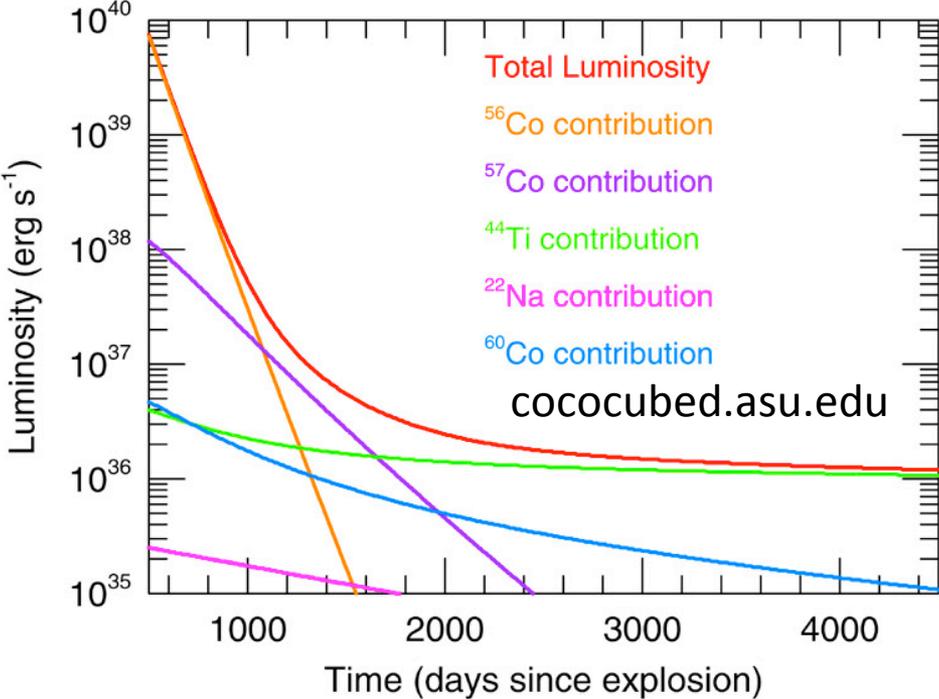
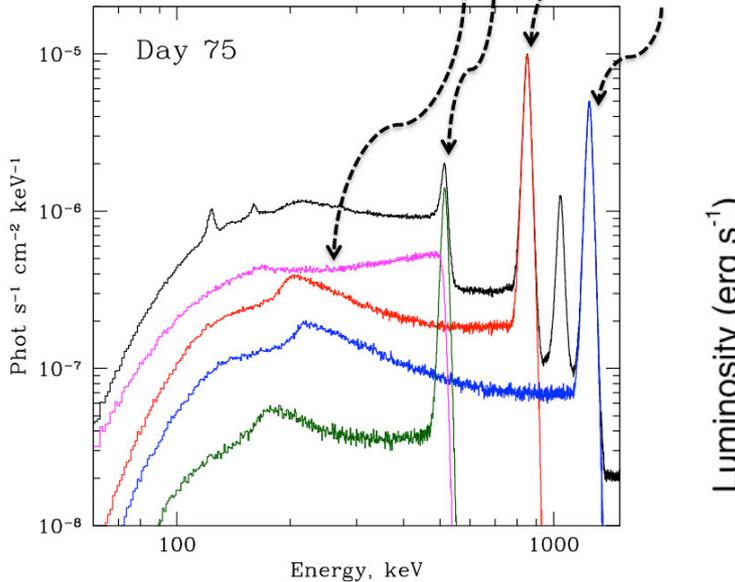
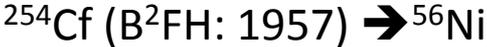


Nearby SF regions in
The MW ISM are
guaranteed sources that
have yet to be detected

CR astrophysics holds
clues to the galactic SFR,
which is essential for GCE

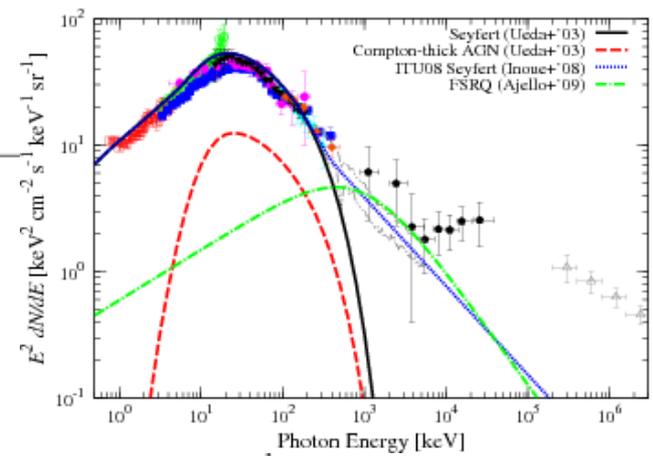
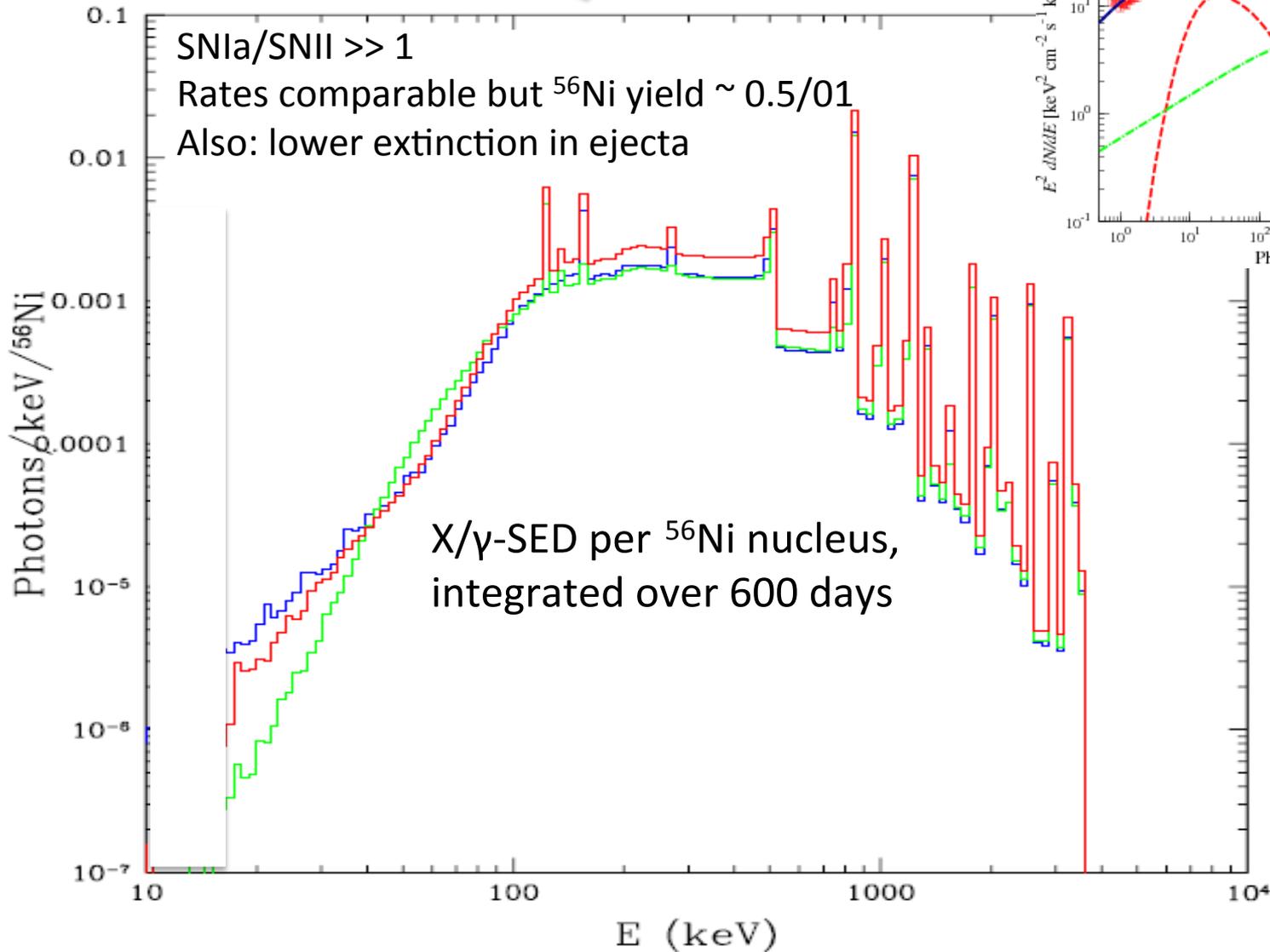


Radioactivities
 keep the SN lights on !



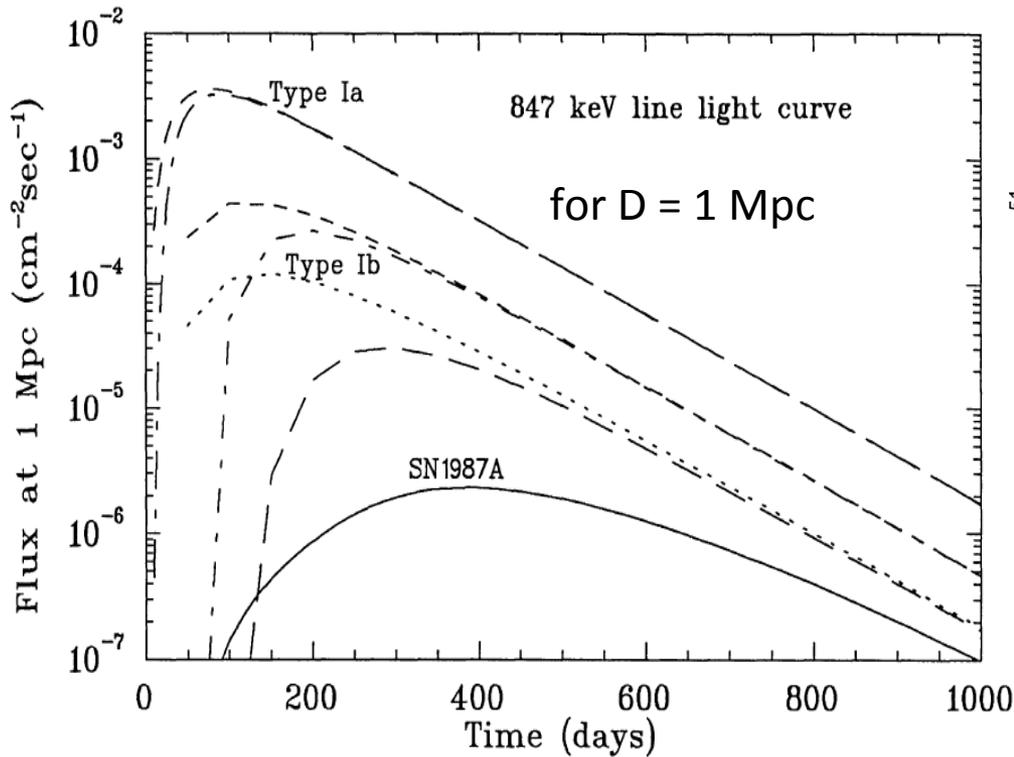
$L(t) \neq L_{\text{radiogenic}}(t)$
 Delayed power model (Clayton92)
 Time-dependent ionization

Time integrated escape SED -> CGB



Diagnosing SNIa models

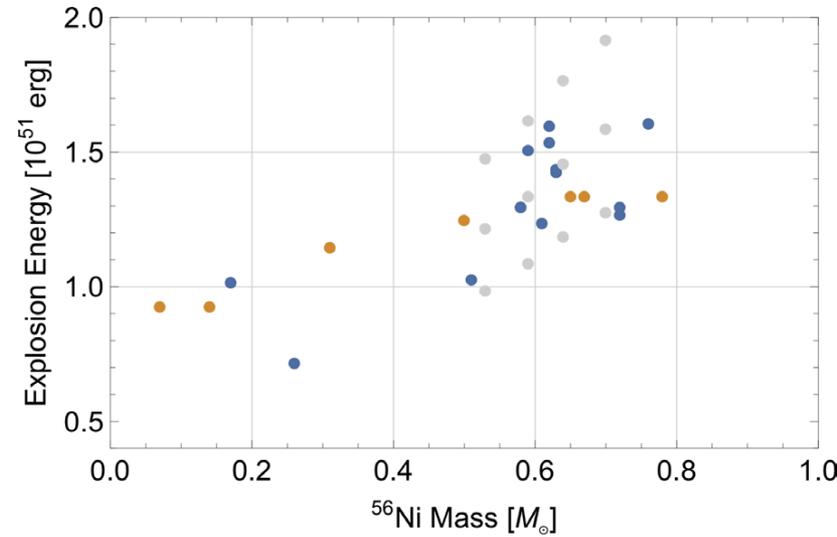
with MC Transport simulations



The, Clayton, Burrows 1991

Calibrating SNIa is crucial for their use as standard candles

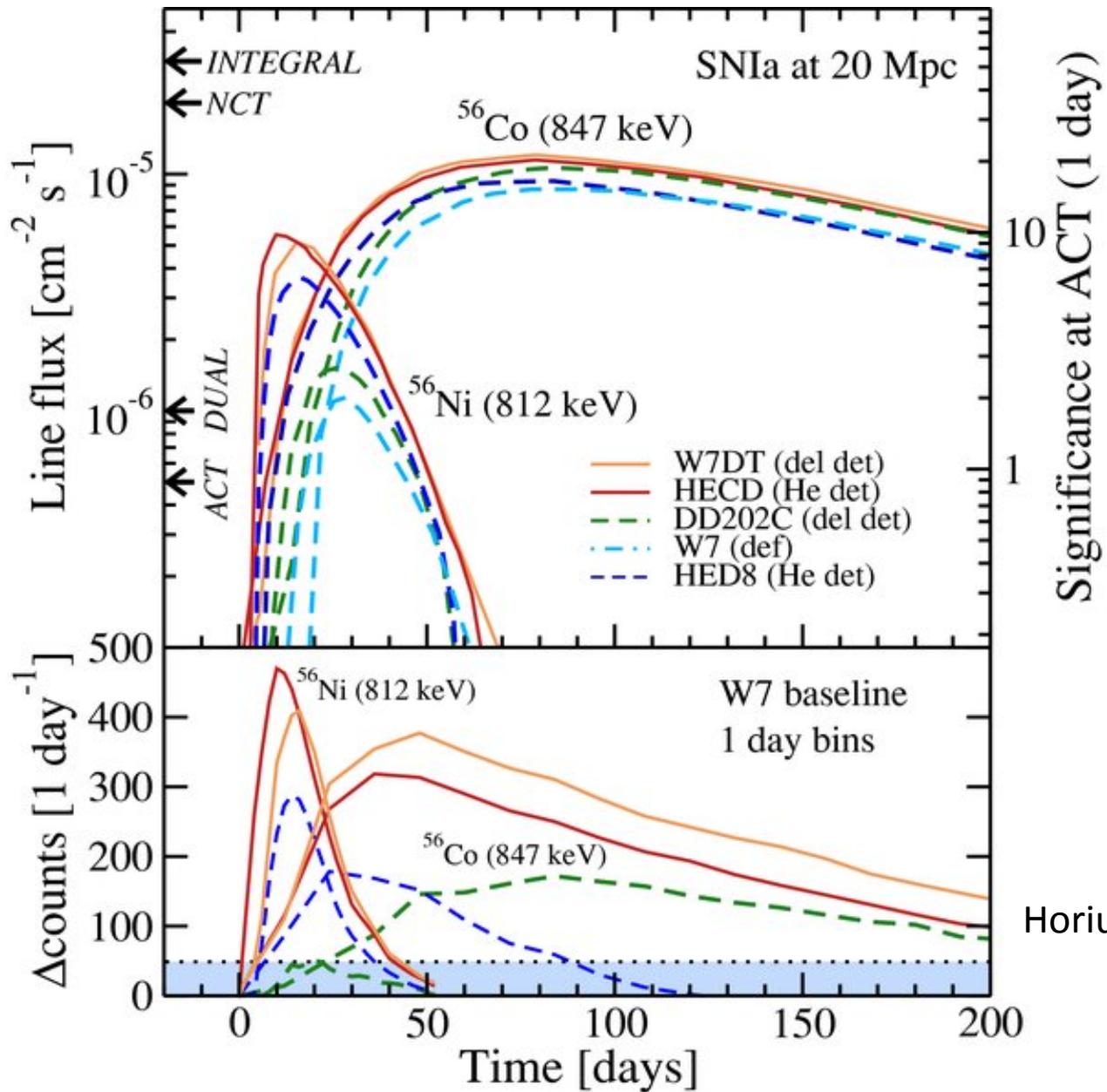
Parameter space is large, but not a scatter cloud (adapted from the LOX collaboration)



Detection distance must be $D_{\text{Ia}} > 30$ Mpc for reasonable rates.

Diagnosing SNIa models

Ejecta mass
Distribution
Kinematics



Horiuchi+2010

847 keV flux [$\text{cm}^{-2} \text{s}^{-1}$]

Horiuchi+2010

10^{-4}

10^{-5}

10^{-6}

Number of SNIa per 10 yrs

- Cosmic rate
- 2000-2009
- 1990-1999
- 1980-1989
- 1970-1979

AMEGO
All-sky Medium Energy Gamma-ray Observatory

14J

1972E

1986G

CGRO (1991~2000)

INTEGRAL (2002~)

1989B 1993af 1998bu 2006E

1979B 1991T 1996ai 1999by

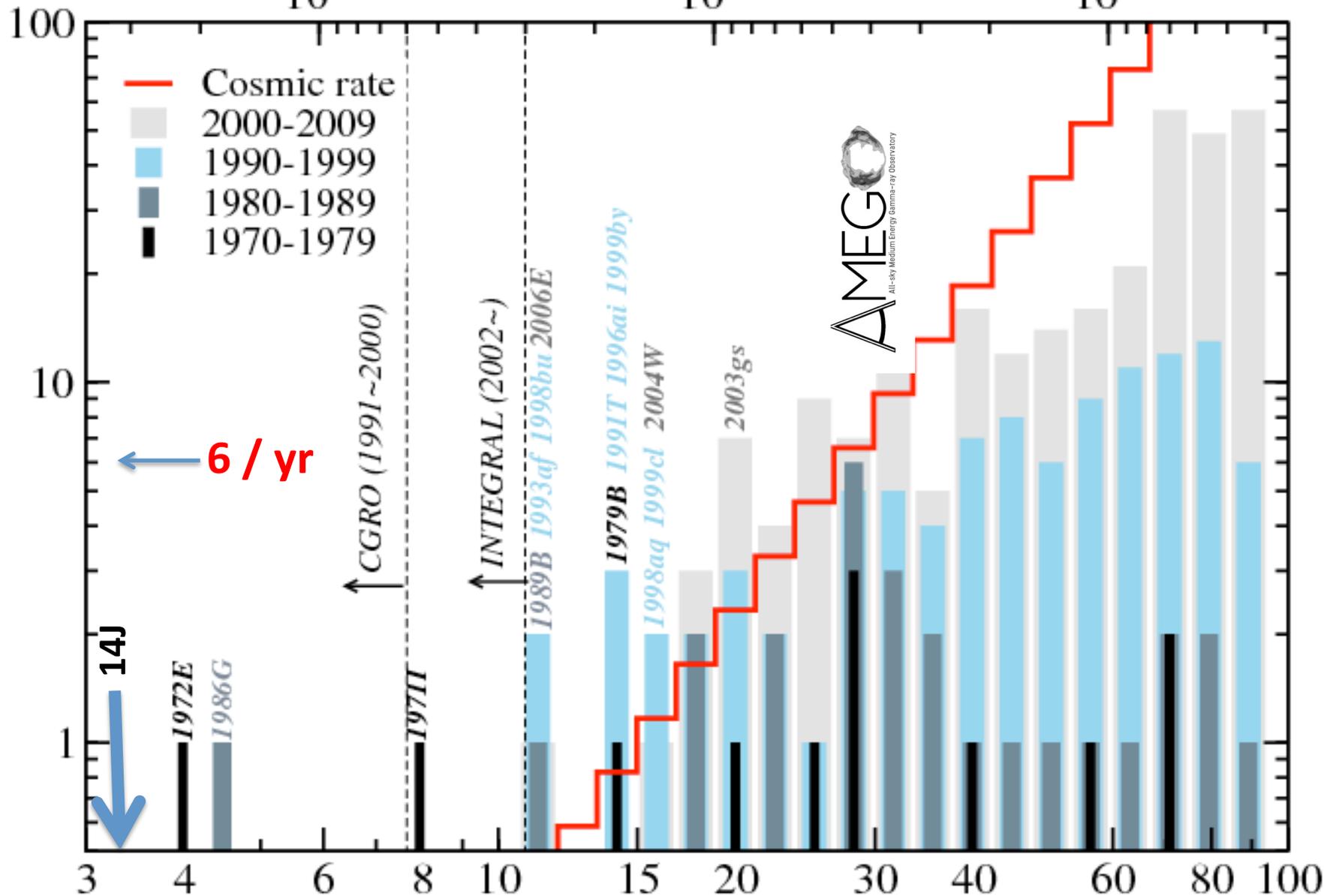
1998aq 1999cl 2004W

2003gs

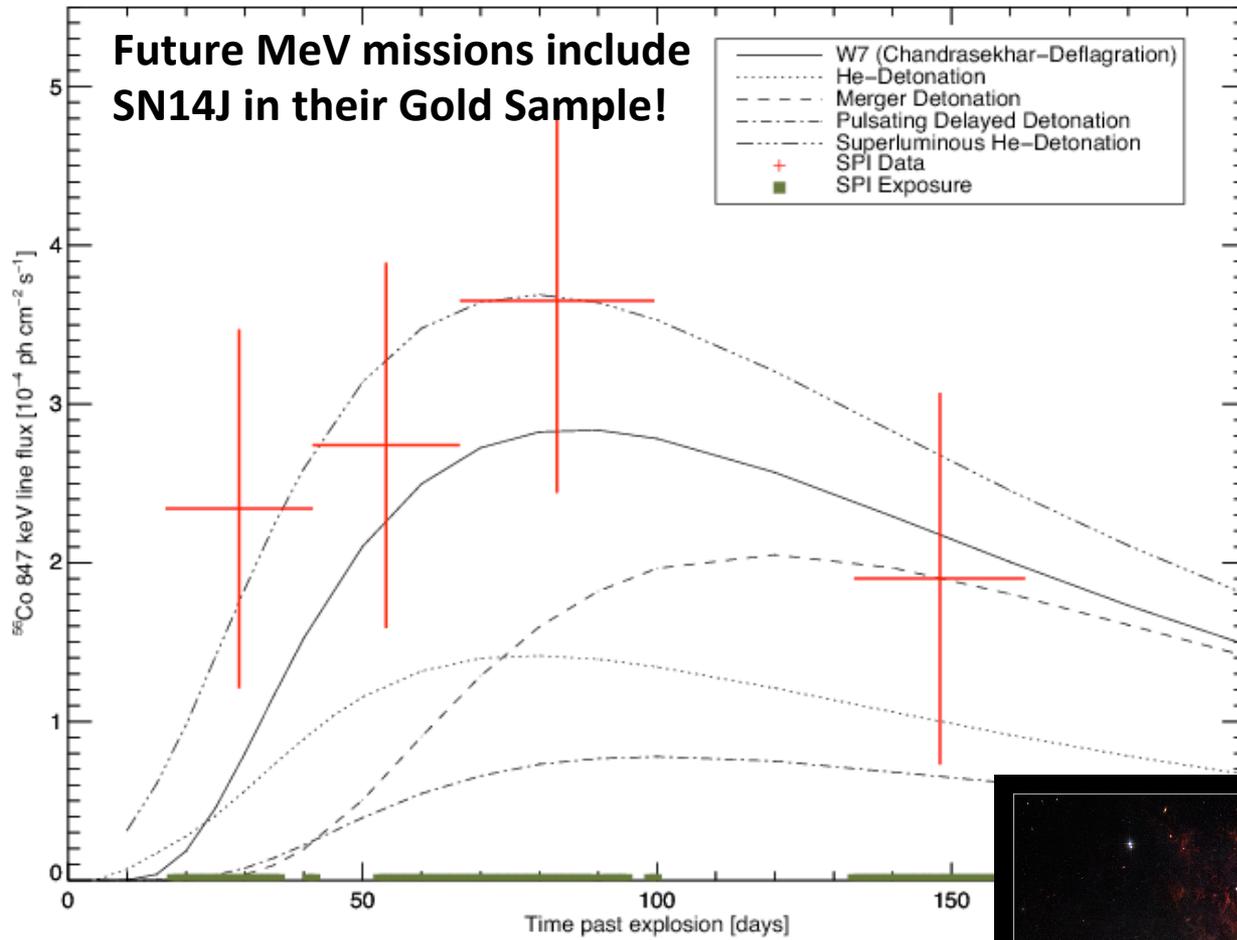
6 / yr

3 4 6 8 10 15 20 30 40 60 80 100

Distance [Mpc]



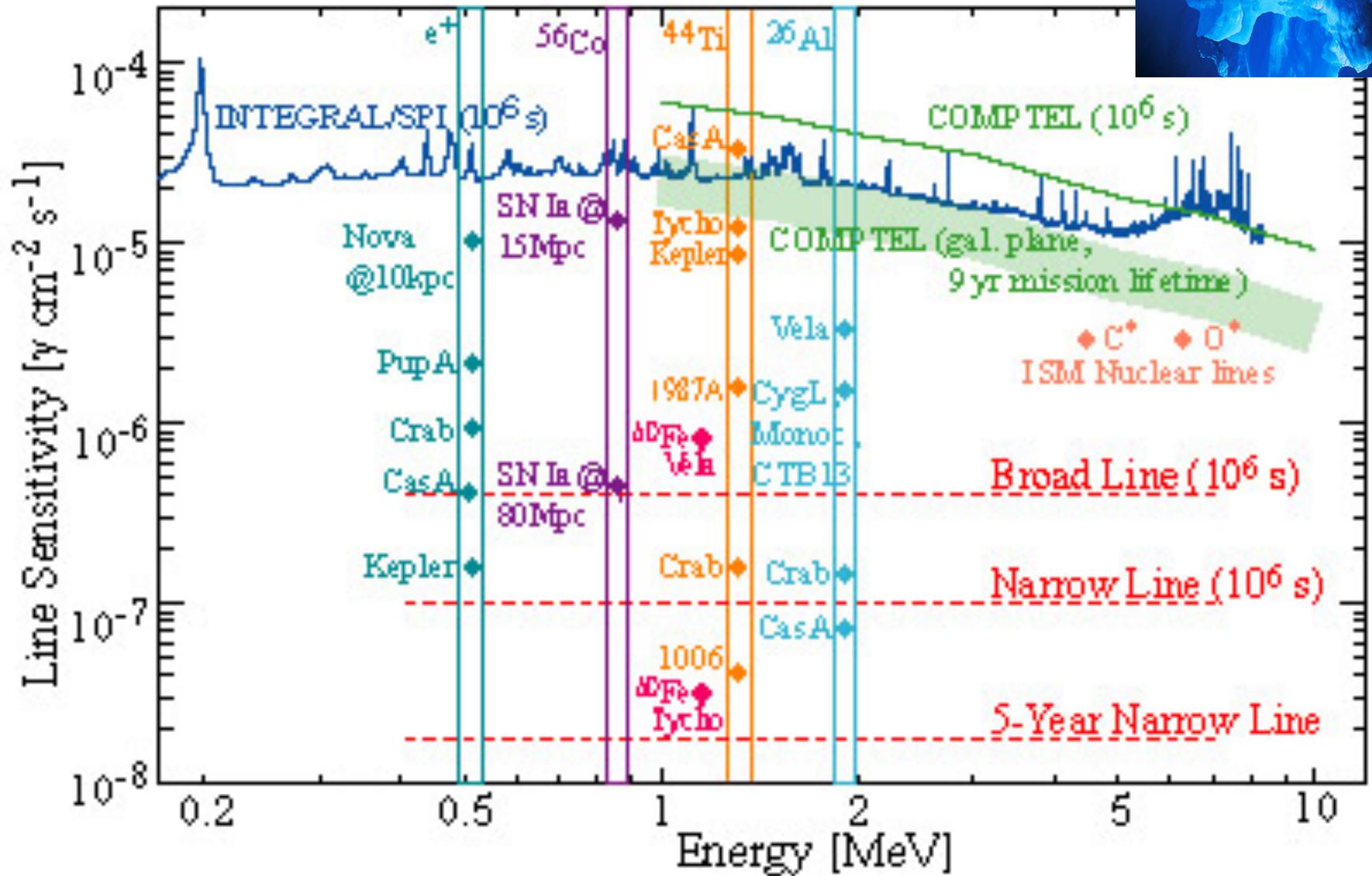
SN2014J at 3.5 Mpc: Diehl et al 2015: INTEGRAL/SPI



Thank You

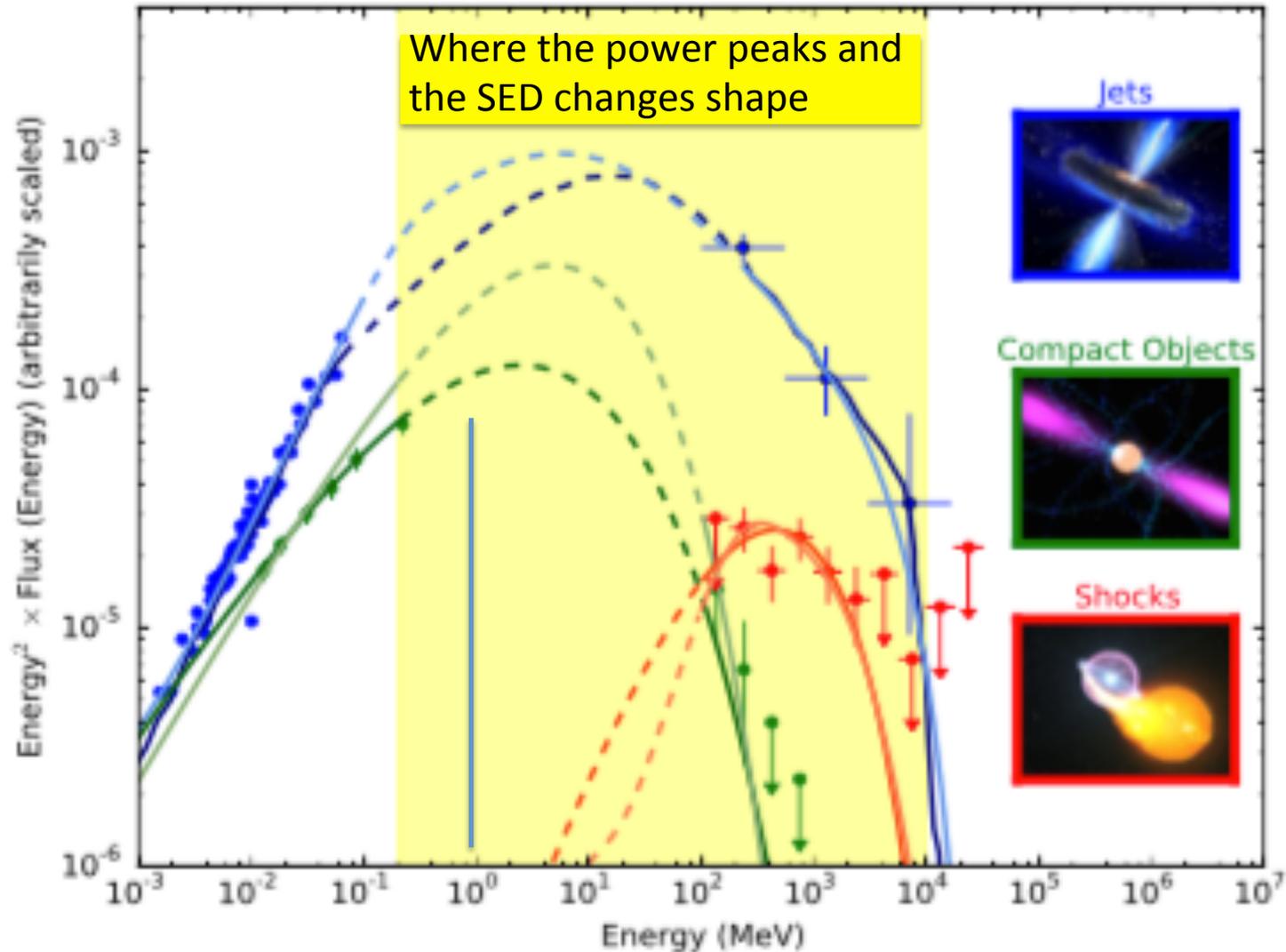
Additional slides (not presented)

The MeV regime is rich, if proper sensitivity can be reached

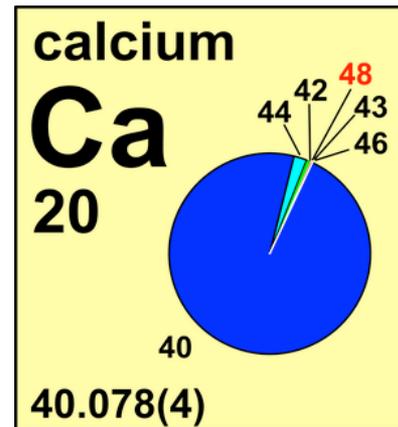
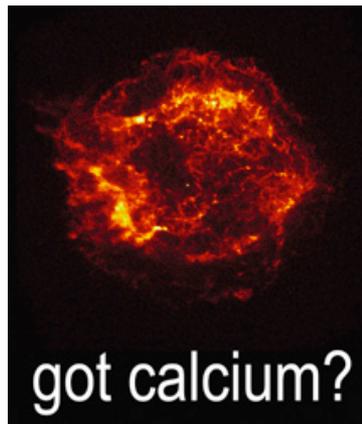
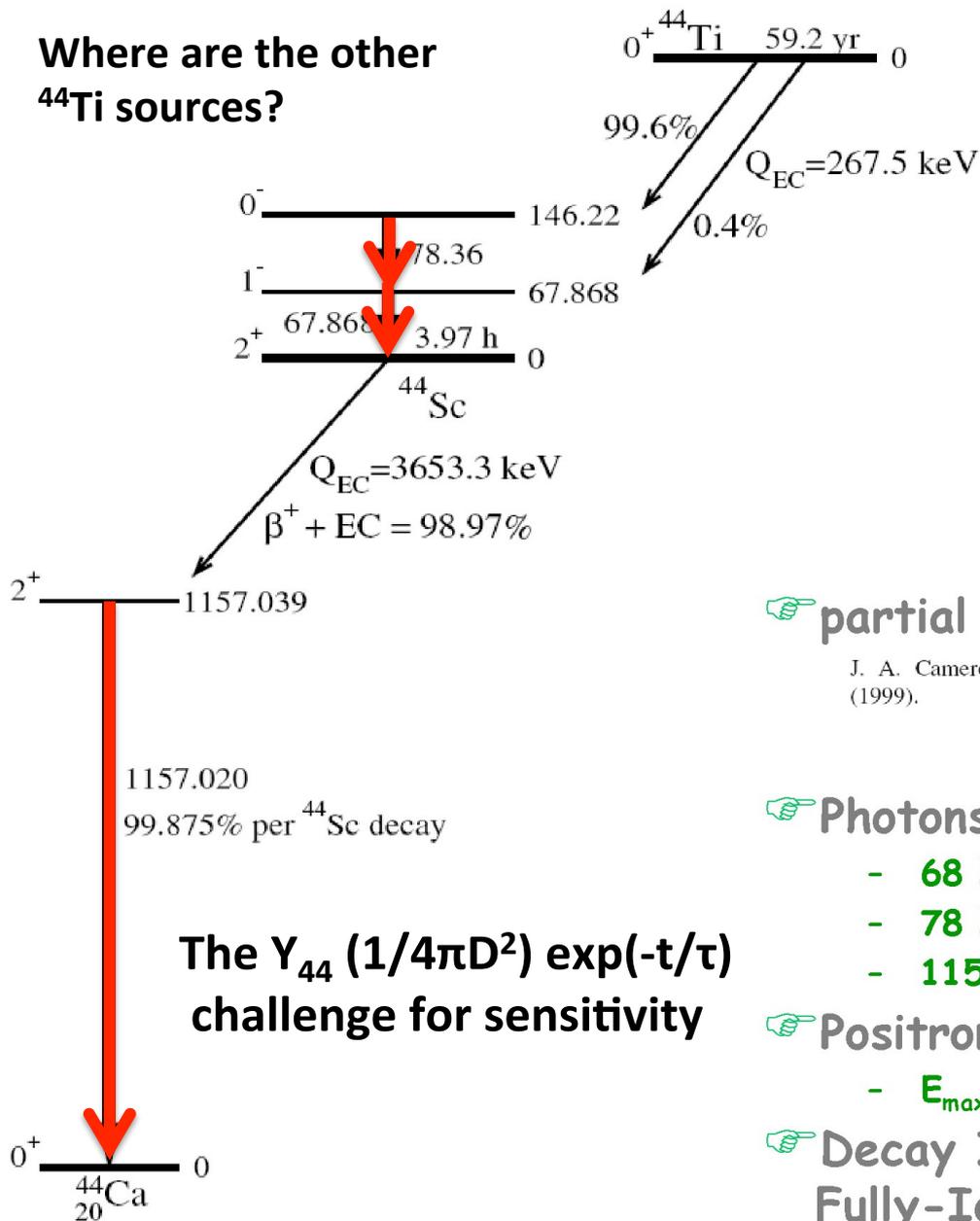


ACT study

Accretion onto compact objects creates ubiquitous disk-jet systems with time-dependent SEDs that exhibit important features in the MeV band that provide critical information.



Where are the other ^{44}Ti sources?



partial level schemes and ^{44}Ti decay

J. A. Cameron and B. Singh, Nucl. Data Sheets **88**, 299 (1999).

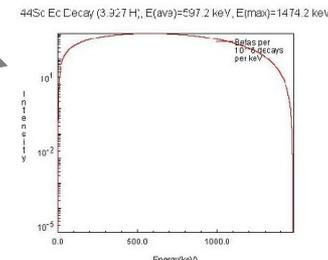
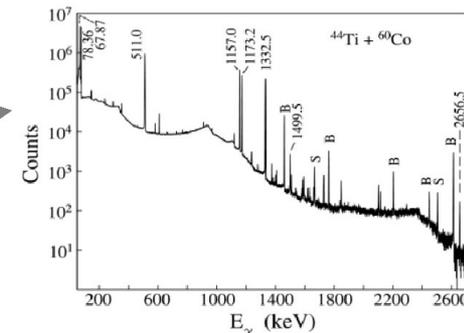
Photons:

- 68 keV 100%
- 78 keV 99.6%
- 1157 keV 99.9%

Positrons

- $E_{\text{max}}=1.47$ MeV 98%

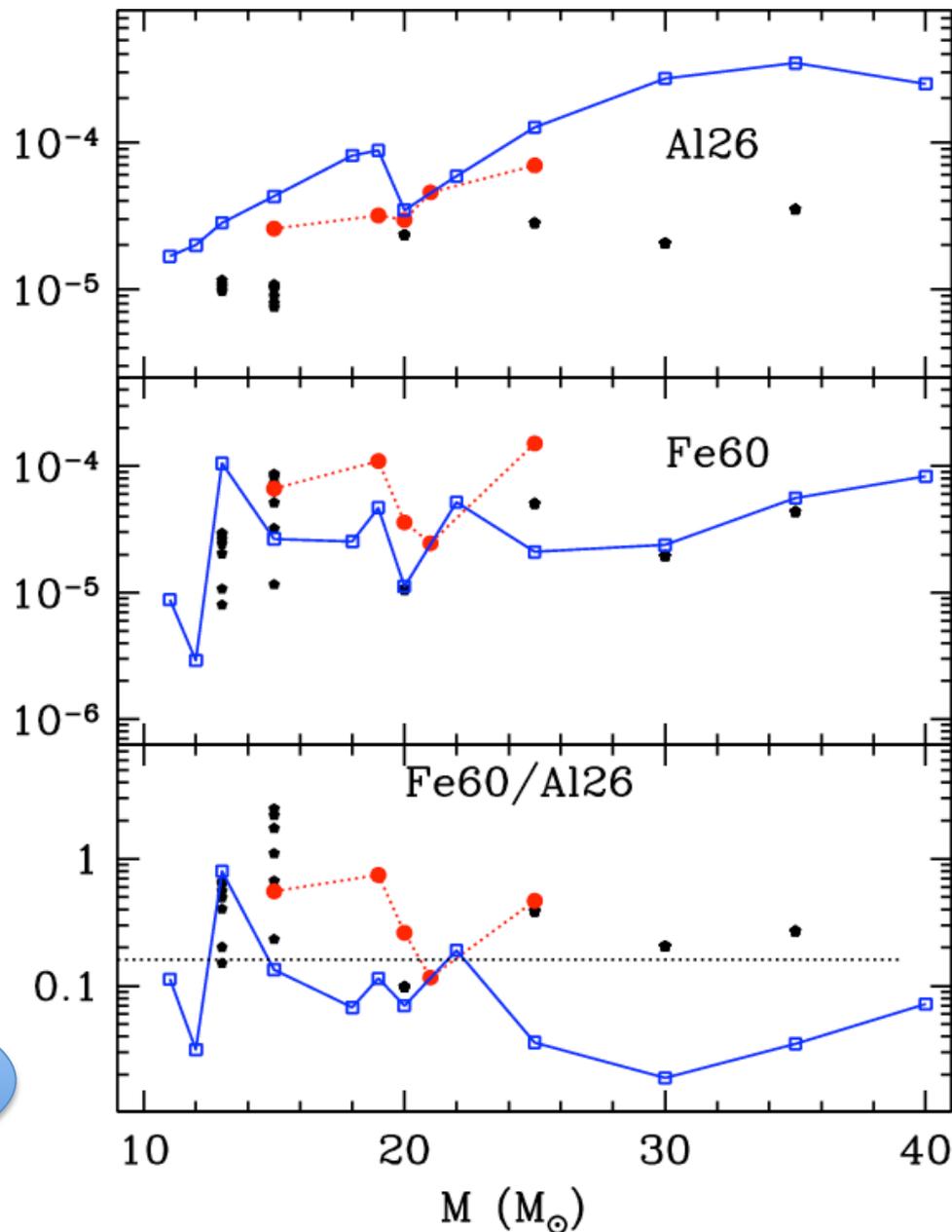
Decay Inhibited for Fully-Ionized ^{44}Ti (EC!)



The Y_{44} ($1/4\pi D^2$) $\exp(-t/\tau)$ challenge for sensitivity

$^{26}\text{Al}/^{60}\text{Fe}$ flux ratio
 $\sim 10\text{-}20\%$ ✓

Diagnostic
for SNI/Novae
decomposition



We need a map